Bowdun Offshore Wind Farm, Offshore EIA Report

Volume 3, Technical Appendix 7.3: Physical Processes Technical Assessment

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Glossary

Defined Term	Definition
Applicant (the)	Bowdun Offshore Wind Farm Limited (BOWFL).
Array Area	The Array Area is the area in which the Offshore Generation Assets will be located.
Bowdun Offshore Wind Farm Limited (BOWFL)	A Special-Purpose Vehicle (SPV) (legal entity) for the purpose of developing the Project. BOWFL are the Applicant for the Offshore Application.
Cumulative Effects	The effects of the Proposed Development assessed together with effects from the Onshore Infrastructure forming the Project as well as one or more different projects on the same receptor/resource.
Effect	Term used to express the consequence of an impact (i.e. the result of change or changes on specific environmental resources or receptors). The significance of an effect is determined by correlating the magnitude of the impact with the importance, or sensitivity of the receptor or resource in accordance with defined significance criteria.
Environmental Impact Assessment (EIA)	Process for the assessment of likely significant environmental effects of a project on the physical, biological and human environment during construction, Operation and Maintenance (O&M) and decommissioning.
Eularian	Describes fluid motion (speed and direction) at (and relative to) a fixed point in space, over time.
Export Cable Corridor	The area seaward of MHWS which connects the Array Area with the Landfall within which the Offshore Export Cables will be installed.
Impact	A change caused by an action that occurs during a project's lifetime.
Inter-Array Cables (IAC)	Cables which link the Wind Turbines to each other and with the Offshore Substation Platforms (OSPs).
Intertidal Area	The area between MHWS and Mean Low Water Springs (MLWS).
Lagrangian	Describes fluid motion (path, speed, direction) through space, over time.
Landfall	The area in which the Offshore Export Cables make Landfall and is also the transitional area between the Offshore Transmission Assets and the Onshore Transmission Assets. Located in the Intertidal Area at Benholm.
Marine Protected Areas (MPAs)	MPAs are designated under the Marine (Scotland) Act 2010 and the Marine and Coastal Access Act (MCAA) 2009. The MPA network protects nationally and internationally important marine wildlife, habitats, geology, and underwater landforms. Scotland's MPAs are significantly important for European, North-East Atlantic, and global MPA networks.
Maximum Design Scenario (MDS)	The scenario within the design envelope likely to result in the greatest impact on a particular topic receptor, and therefore the one that should be assessed for that topic receptor.
Mean High Water Springs (MHWS)	The average tidal height throughout the year of two successive high waters during those periods of 24 hours when the range of the tide is at its greatest.

Defined Term	Definition
Mean Low Water Springs (MLWS)	The average tidal height throughout the year of two successive low waters during those periods of 24 hours when the range of the tide is at its greatest.
Offshore Environmental Impact Assessment (EIA) Report (hereafter, 'Offshore EIA Report')	Document prepared to report the findings of the EIA for the Proposed Development and produced in accordance with the EIA Regulations. The Offshore EIA Report is submitted to support the Offshore Application for the Proposed Development, and to comply with EIA Regulations.
Offshore Export Cables	Subsea cables used to transmit electricity generated offshore by the Wind Turbines from the OSPs to shore. The Transition Joint Bay (TJB) is the location where the Offshore Export Cables terminate, and the onshore cabling begins.
Offshore Infrastructure	All of the Offshore Infrastructure associated with the Proposed Development that is located seaward of MHWS, comprising the Offshore Generation Assets and the Offshore Transmission Assets.
Offshore Substation Platform(s) (OSPs)	OSPs comprise the support structure, topside and electrical components used for collecting and/or converting electricity generated by the Wind Turbines for transmission by the Offshore Export Cables.
Operation and Maintenance (O&M)	The phase of the Proposed Development following completion of construction. This phase of development includes routine inspections, repairs and replacement of infrastructure and equipment (including Interconnector Cables and IACs), Scour Protection replenishment or replacement, major component replacement, painting and/or other coating works, removal of marine growth, and replacement of access ladders.
Plan Option Area (POA)	A location identified in the Sectoral Marine Plan (SMP) as a preferred area for commercial scale offshore wind development.
Project (the)	An overarching term for the Bowdun Offshore Wind Farm (Bowdun OWF) comprising the offshore and onshore infrastructure required to generate and transmit electricity from the Array Area to the onshore Grid Connection Point (GCP). The Project includes the Offshore Generation Assets, the Offshore Transmission Assets and the Onshore Transmission Assets.
Project Design Envelope (PDE)	A description of the range of possible elements that make up the design options for the Proposed Development under consideration when the exact engineering parameters are not yet known.
Proposed Development	Term used to define the Offshore Infrastructure associated with the Project seaward of MHWS for which consent is being sought. Further details of the parameters are included in Volume 1, Chapter 3: Project Description.
Scour Protection	Protective materials installed to avoid sediment being eroded away from the base of the foundations and/or buried subsea cable due to the flow of water.
Significance	Effect factor that is determined by the magnitude of impact along with the sensitivity of the receptor.
Special Areas of Conservation (SACs)	SACs are areas designated for the conservation of certain plant and animal species listed in the Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora.

Defined Term	Definition
Special Protection Areas (SPAs)	SPAs are sites that are designated to protect rare or vulnerable birds (as listed on Annex I of the Directive 2009/147/EC on the conservation of wild birds), as well as regularly occurring migratory species.
Spring Tidal Excursion	The distance suspended sediment is transported prior to being carried back on the returning tide.
Study Area	For each environmental topic, the baseline environment will be characterised, and the potential environmental impacts will be described within a topic-specific study area. Specific study areas are defined for each topic and are based on the maximum spatial extent across which potential impacts of the Project may be experienced by the relevant receptors (i.e. Zone of Influence).
Thistle Wind Partners (TWP)	Company established for the development of the Project.
Tidal Ellipse	The illustration of the variance of tidal currents in horizontal space.
Wind Turbines	Structures comprising of a tubular tower, rotor blades, and a nacelle which houses the Wind Turbine generator.

Acronyms

Acronym	Definition
ABPmer	ABP Marine Environmental Research
ASL	Above Sea Level
BGS	British Geological Survey
DirM	Mean Wave Direction
DNV	Det Norske Veritas
EIA	Environmental Impact Assessment
HDD	Horizontal Directional Drilling
IAC	Inter-Array Cable
KC	Keulegan-Carpenter
LAT	Lowest Astronomical Tide
MDS	Maximum Design Scenario
MFE	Mass Flow Excavator
MHWS	Mean High Water Spring
MLWS	Mean Low Water Spring
MPA	Marine Protected Area
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
O&M	Operation and Maintenance
PDE	Project Design Envelope
POA	Plan Option Area
RP	Return Period

Acronym	Definition
SAC	Special Area of Conservation
SMP	Sectoral Marine Plan
SPA	Special Protection Area
SSC	Suspended Sediment Concentration
ST	Sand Transport
Tp	Peak Wave Period
Tz	Zero Crossing Wave Period
TWP	Thistle Wind Partners Limited
UK	United Kingdom
UTM	Universal Transverse Mercator

Table of Units

Units	Definition
kg	Kilogram
kg/s	Kilogram per second
kg/m^3	Kilogram per cubic metre
km	Kilometre
km^2	Square kilometre
m	Metre
m/hr	Metre per hour
m^2	Square Metre
m^3	Cubic Metre
$m^3/day/m$	Cubic Metre per day per metre
$m^3/s/m$	Cubic Metre per second per metre
mg/l	Milligram per litre
mm	Millimetre
m/s	Metre per second
MW	MegaWatt
s	Second
Hs	Significant wave height
°	Degree
%	Percent
µm	Micrometre
U_{0m}	Peak Orbital Velocity

1 Introduction

1.1.1 This Physical Processes Technical Report presents the supporting technical analysis underpinning the Physical Processes Environmental Impact Assessment (EIA) for the offshore elements of the Bowdun Offshore Wind Farm (OWF) Project (hereafter referred to as the Proposed Development). The Proposed Development covers the Option Lease Area (OLA) comprises of the Array Area, which is located in the E3 Plan Option Area (POA) detailed in the Scottish Sectoral Marine Plan (SMP) (Scottish Government, 2020), and the Export Cable Corridor. The Array Area is located 38 km from the Aberdeenshire coast at its closest point, covering an area of 187 km^2. The Proposed Development will comprise of Wind Turbines (fixed foundations), Inter-Array Cables (IACs), Offshore Substation Platforms (OSPs), Interconnector Cables, Offshore Export Cables and any necessary scour/cable protection. The Export Cable Corridor will include a maximum of three High Voltage Alternating Current (HVAC) Offshore Export Cables, each with a length of up to 70 km and will make Landfall at Benholm, Aberdeenshire

1.1.2 The assessments presented in this technical report have been informed by:

- the collation and analysis of baseline information (as set out in Volume 3, Technical Appendix 7.1: Physical Processes Baseline Environment); and
- hydrodynamic, wave and sediment plume modelling (the setup of which is set out in Volume 3, Technical Appendix 7.2 Model Design and Validation).

1.1.3 These approaches have been developed to infer the potential changes relative to the baseline (existing) coastal and marine environment caused by the construction, Operation & Maintenance (O&M) and decommissioning of the Proposed Development, specifically changes to:

- the suspended sediment concentrations (SSC), bed levels and sediment type (Section 2);
- the wave regime (Section 3);
- the tidal regime and tidally driven sediment transport regime (Section 4); and
- scour and seabed alteration (Section 5).

1.1.4 The information from this technical report informs the technical analysis and the assessment of the likely significant environmental effects of the Proposed Development on Physical Processes across the Physical Processes Study Area (Figure 1.1). This report accompanies the EIA Chapter provided in Volume 2, Chapter 7: Physical Processes to support the consent application for the Proposed Development.

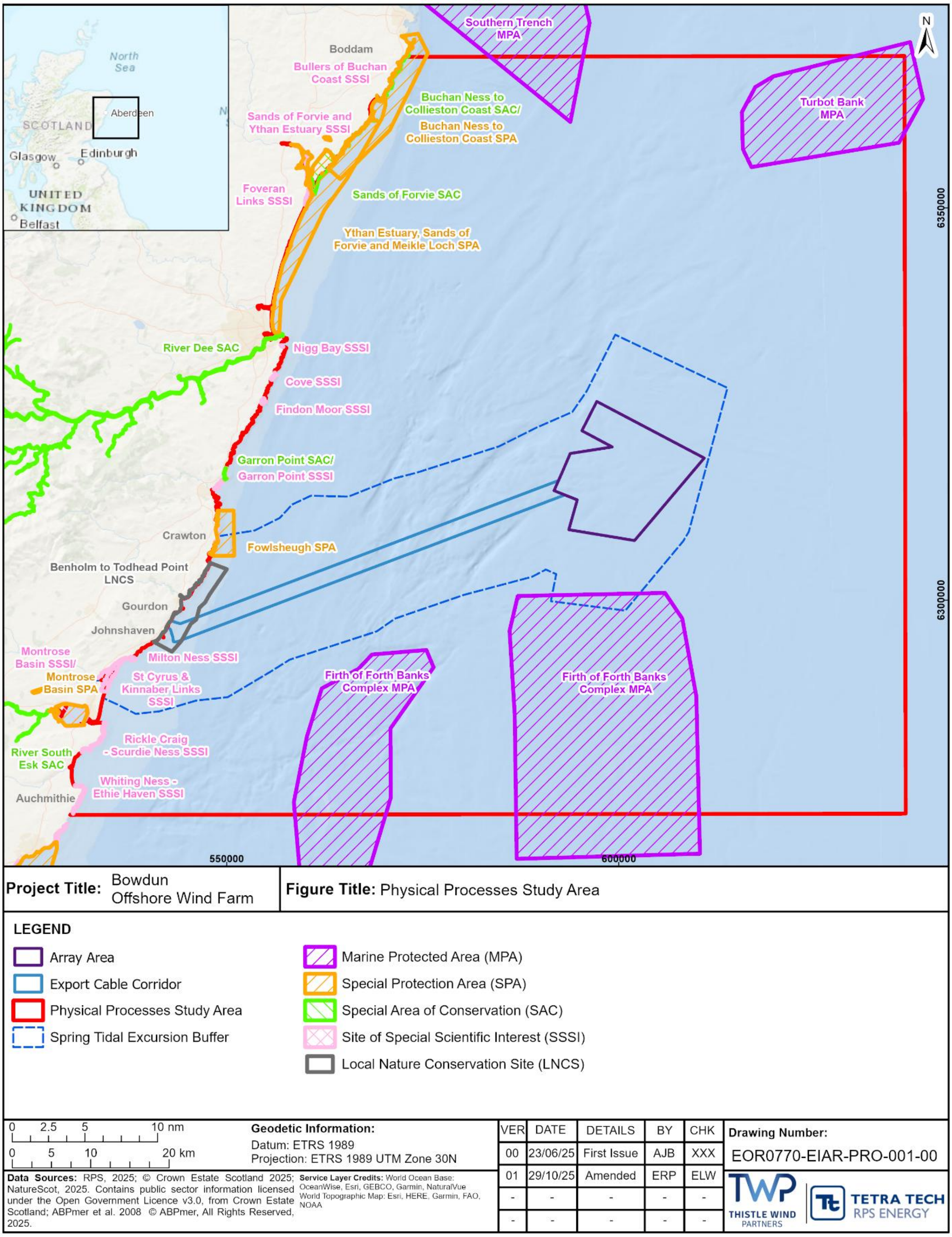

Figure 1.1: Physical Processes Study Area

2 Sediment Disturbance

2.1 Overview

2.1.1 This section presents a study of the likely nature of sediment plumes (footprint, concentration, duration) and resulting sediment deposition (footprint and thickness) as a result of Maximum Design Scenario (MDS) (Volume 2, Chapter 7: Physical Processes) sediment disturbance during the construction phase of the Proposed Development.

2.1.2 Maps of potential increases in SSC and thickness of sediment deposition are produced for various sediment disturbance scenarios and tidal conditions.

2.1.3 For each activity, the rate and duration of sediment disturbance and the total sediment volume are calculated for individual occurrences and for all occurrences of the activity, including the range of design permutations (e.g. a smaller number of larger foundations or a larger number of smaller foundations). Scenarios are identified that are likely to correspond to the realistic MDS in terms of instantaneous and overall effects. The effect of all other options in the Project Design Envelope (PDE) is therefore expected to be equal to or less than the results presented in this report.

2.1.4 The sediment plume modelling described in this section has been undertaken using the MIKE21FM (flexible mesh) Particle Tracking software package from the Danish Hydraulic Institute, which has been developed specifically for application in oceanographic, coastal and estuarine environments. Particles representing discrete amounts of sediment are released and subject to advection and dispersion within a tidal flow simulation of the wider study area.

2.1.5 When used by an experienced modeller, and in conjunction with suitable data inputs, these models provide reliable and realistic representations of both baseline environmental conditions, and the potential effects of offshore wind farm infrastructure and other construction-related activities.

2.2 Sediment Disturbance Scenarios

2.2.1 The following MDS sediment releases have been considered:

- five activity types:
    - pre-lay cable trenching using a Mass Flow Excavator (MFE) tool at the seabed;
    - sandwave clearance using a MFE tool at the seabed;
    - drill arisings release at the water surface during drilling for foundations;
    - dredge spoil disposal at the water surface related to seabed preparation for cables or foundations (including sandwave clearance);
    - bentonite release following Landfall punch-out via trenchless techniques (e.g. Horizontal Direct Drilling (HDD));

- at locations in the Array Area, along the length of and in the middle of the Export Cable Corridor, and near to the Landfall, as applicable; and
- occurring (separately) on and around representative spring and neap tidal periods.

2.2.2 The following cumulative sediment releases have also been considered for representative spring and neap tidal periods:

- drill arisings release at the water surface during drilling for foundations within the proposed Morven North wind farm array area.
- sandwave clearance using an MFE tool at the seabed within the proposed Morven North wind farm array area; and
- dredge spoil disposal at the water surface related to seabed preparation for cables or foundations (including sandwave clearance) within the proposed Morven North wind farm array area.

2.2.3 A range of information has been used to characterise the nature of the surficial and sub-seabed sediments within the Array Area and Export Cable Corridor. These include benthic samples provided by the British Geological Survey (BGS) (BGS, 2025), as well as interpreted geophysical data collected as part of the Bowdun geophysical site characterisation survey work (G-Tec, 2025a,b). The range of sediment grain size categories used in the model are shown in Table 2.1.

Table 2.1: Sediment Grain Size Fraction Used

Sediment Fraction Name	Representative Grain Size (µm)	Representative Settling Velocity (m/s)
Gravel	~8,000	0.5
Coarse sand	~1,000	0.1
Medium sand	~250	0.03
Fine sand	~150	0.01
Silt	~10	0.0001

2.2.4 The subsequent plume settlement and dispersion are simulated over a further three-day period following the end of the sediment disturbance to characterise the persistence and rate of dispersion of the plume. Where fines are present, a three-day period is sufficient for the purposes of the EIA assessment, as consistent with the approach taken for several similar recent offshore wind farm plume modelling studies undertaken by ABPmer (e.g. Awel y Môr Offshore Wind Farm Limited (ABPmer, 2021); Five Estuaries Offshore Wind Farm Limited (ABPmer, 2024)), and can be seen from the very small amount of sediment that remains in suspension three days from release. Sands and gravels will have redeposited to the seabed within a much shorter timescale.

2.2.5 Table 2.2 provides a summary of the sediment plume scenarios, the location of each release, the mass of sediment and the type of sediment at each site.

Table 2.2: Sediment Disturbance Scenarios

Scenario No.	Mean Tidal Condition	Activity	Release Location (UTM 30)	Rate and Duration of Release	Grain Size Fractions (% of Total)
Array Area					
1	Neap	Pre-lay Trenching (MFE)	L-shaped route in Array Area	795 kg/s for 24 hours 50 min, 400 m/hr, @ 3 m above seabed. Rate assumes 100% release of material from the trench	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
2	Spring				
3	Neap	Sandwave clearance (MFE)	Southern boundary of the Array Area (597857, 6308405)	1,000 kg/s for 12 hours 20 min, static, @ 3 m above seabed	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
4	Spring				
5	Neap	Drilling of foundations	Two neighbouring foundation locations at the southern boundary of the Array Area (597857, 6308405 and 598150, 6309490)	260.1 kg/s for 22.5 hours, static, @ water surface	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
6	Spring				
7	Neap	Dredge spoil disposal	Southern boundary of the Array Area (597857, 6308405)	1,749,000 kg, sudden release, static, @ water surface	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
8	Spring				
Export Cable Corridor					
9	Neap	Pre-lay Trenching (MFE)	Export Cable Corridor (along whole length)	795 kg/s for ~5.5 days, 400 m/hr, @ 3 m above seabed. Rate assumes 100% release of material from the trench	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
10	Spring				
11	Neap	Sandwave clearance (MFE)	Centre of Export Cable Corridor (571415, 6306188)	1,000 kg/s for 12 hours 20 min, static, @ 3 m above seabed	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
12	Spring				

Scenario No.	Mean Tidal Condition	Activity	Release Location (UTM 30)	Rate and Duration of Release	Grain Size Fractions (% of Total)
13	Neap	Dredge spoil disposal	Centre of Export Cable Corridor (571415, 6306188)	1,749,000 kg, sudden release, static, @ water surface	10% gravel, 30% coarse sand, 30% medium sand, 20% fine sand, 10% silt
14	Spring				
Nearshore Region					
15	Neap	Sandwave clearance (MFE)	~2.5 km from Landfall (544948, 6296254)	1,000 kg/s for 12 hours 20 min, static, @ 3 m above seabed	10% gravel, 20% coarse sand, 50% medium sand, 10% fine sand, 10% silt
16	Spring				
17	Neap	Dredge spoil disposal	~2.5 km from Landfall (544948, 6296254)	1,749,000 kg, sudden release, static, @ water surface	10% gravel, 20% coarse sand, 50% medium sand, 10% fine sand, 10% silt
18	Spring				
19	Neap	Landfall punch-out	Exit pit (542880, 6296983)	79.8 kg/s for 1 hour, static, @ 5 m above seabed	100% silt
20	Spring				
Cumulative Releases (Morven North OWF)					
21	Neap	Sandwave clearance (MFE)	Closest point within Morven North OWF to the Bowdun Array Area aligned along the tidal axis (611227, 6300090)	1,000 kg/s for 12 hours 20 min, static, @ 3 m above seabed	10% gravel, 20% coarse sand, 30% medium sand, 20% fine sand, 20% silt
22	Spring				
23	Neap	Drilling of foundations	Two neighbouring foundation locations in the Morven North array area (611227, 6300090 and 61127, 6298854)	260.1 kg/s for 22.5 hours, static, @ water surface	10% gravel, 20% coarse sand, 30% medium sand, 20% fine sand, 20% silt
24	Spring				
25	Neap	Dredge spoil disposal	Closest point within Morven North OWF to the Bowdun	1,749,000 kg, sudden release, static,	10% gravel, 20% coarse sand, 30% medium sand, 20% fine sand, 20% silt

Scenario No.	Mean Tidal Condition	Activity	Release Location (UTM 30)	Rate and Duration of Release	Grain Size Fractions (% of Total)
26	Spring		Array Area aligned along the tidal axis (611227, 6300090)	@ water surface	

Release Location Assumptions

2.2.6 The pre-lay trenching MFE in Scenarios 1 and 2 is represented as a moving source near the southern boundary of the Array Area. This was chosen because it is the closest point to the Firth of Forth Banks Complex Marine Protected Area (MPA), so provides the MDS in terms of impact on protected features, all other designated areas are further than a spring tidal excursion ellipse from the Array Area. The release period is over a 24 hr 50 min period (i.e. two full tidal cycles), moving initially from west to east (across the current axis) for one tide (including one ebb and one flood) and then from south to north (with the current axis) for one tide, at a constant (maximum) rate of 400 m/hr (covering ~10 km during the simulation period).

2.2.7 The location of the static releases in Scenarios 3 to 8 (local sandwave clearance, drilling and dredge spoil disposal) is at an approximately central point along the southern boundary of the Array Area, at the closest point to the Firth of Forth Banks Complex MPA.

2.2.8 The pre-lay trenching MFE in Scenarios 9 and 10 is represented as a moving source over a 132 hour period (i.e. approximately ten full tidal cycles), moving from the Landfall to the edge of the Array Area, at a constant (maximum) rate of 400 m/hr (covering ~53 km during the simulation period).

2.2.9 The location of the static releases in Scenarios 11 to 14 (local sandwave clearance and dredge spoil disposal) is within the central point of the Export Cable Corridor.

2.2.10 The location of the static releases in Scenarios 15 to 18 (local sandwave clearance and dredge spoil disposal) is in the nearshore area, approximately 2.5 km offshore of the Landfall for the Export Cable Corridor. The location of the static releases in Scenarios 19 and 20 (Landfall punch-out) is at one of the seaward exit point locations specified in Volume 1, Chapter 3: Project Description.

2.2.11 The locations of the static release in Scenarios 21 to 26 (local sandwave clearance, drilling and dredge spoil disposal) were chosen as the closest point in the proposed Morven North array area that aligns with the Bowdun Array Area along the tidal axis, in order to capture the worst-case scenario for cumulative impacts.

Pre-Lay Trenching (MFE) Assumptions

2.2.12 The mass of sediment placed into suspension by pre-lay cable trenching with an MFE tool was estimated as follows:

- The amount of material removed from a V-shaped trench (6 m wide and 1.5 m deep) is calculated as 4.5 m^3 of sediment per one metre trenched.
- This is converted to a mass of sediment removed by applying a dry bulk density of 1,590 kg/m^3 (0.6 solidity ratio x 2,650 kg/m^3 solid density) for uniform sand (4.5 m^3 x 1,590 kg/m^3 = 7,155 kg).
- The rate of trenching is assumed to be 400 m/hr. This allows a sediment release rate of 795 kg/s to be calculated ((7,155 kg x 400)/(60 x 60) = 795 kg/s).
- It is conservatively assumed that 100% of the material in the trench is fluidised and displaced.

Sandwave Clearance (MFE) Assumptions

2.2.13 The rate of sediment disturbance (1,000 kg/s) by an active MFE tool was conservatively estimated based on the MDS trench cross section dimensions, the speed of progress of the tool, and the bulk density of the local sediment type at each of the three locations. This estimate is conservative in comparison to the working rate of the device (1,000 m^3/hr, which corresponds to approximately 440 kg/s).

2.2.14 All of the disturbed sediment is initially released at 3 m above the local seabed level. In practice, an MFE will also displace some proportion of sediment from the trench to the adjacent seabed through liquefaction and near-bed gravity flow (rather than necessarily putting sediment into suspension higher into the water column). This scenario therefore provides a conservative representation of the near-field effect of the MFE process.

Drilling Assumptions

2.2.15 The mass of sediment placed into suspension by drilling was estimated as follows:

- The foundation type that gave the greatest drill arising volume for a single drill event was chosen as the MDS.
- 7,952 m^3 of spoil is produced per pile drilled, assuming a drill diameter of 15 m and drill depth of 45 m ((π x (15 m / 2)^2) x 45 m = 7,952 m^3).
- This is converted to a mass of sediment released by applying a soil (rock) density of 2,650 kg/m^3. 7,952 m^3 x 2,650 kg/m^3 = 21,072,800 kg.
- The rate of drilling is assumed to be 22.5 hours per foundation (81,000 seconds). The longest drill time provides the MDS for spatial footprint of the plume, allowing potential to impact surrounding designated areas to be assessed.
- The rate of sediment release is calculated as 260.1 kg/s (21,072,800 kg /81,000 seconds).

- A maximum of two drilling events may occur concurrently. In terms of intensity, the MDS will be if these events are next to each other.
- Concurrent release locations are spaced 1,083 m apart (equal to minimum turbine spacing) and aligned with tidal current axis to maximise overlap of the plumes.

Dredge Spoil Release Assumptions

2.2.16 The mass of sediment placed into suspension by a spoil release scenario is estimated as follows:

- A representative large hopper sediment volume of 11,000 m^3 is released suddenly (within a single 10-minute timestep in the model).
- The total mass of sediment released is estimated as 11,000 m^3 sediment x 0.6 solidity ratio x 2,650 kg/m^3 solid density = 17,490,000 kg.
- The majority (90%) of the sediment volume is realistically assumed to descend directly to the bed in the 'active phase' of the plume as a single mass of sediment, which does not contribute to the more diffuse SSC effects considered by the plume model.
- The remaining 10% of sediment (10% of 17,490,000 kg = 1,749,000 kg) is assumed to be dispersed into the water column at the point of release, allowing sediment grains to remain in suspension for longer, forming the 'passive phase' of the plume.
- It is assumed that the sediment is sufficiently mixed by the dredging process that the proportion of sediment fractions in the active and passive phases are the same as the original seabed sediment.

2.2.17 The proportion of sediment assumed to be in the passive and active phases is a conservatively representative value that may vary in practice. The chosen value (up to 10% in the passive phase) is consistent with studies on this topic by Becker *et al.* (2015).

Landfall Punch-Out Assumptions

2.2.18 A trenchless technique, such as HDD, is the preferred option to transition the Offshore Export Cable to the onshore export cables at Landfall. The release of drilling fluid into the coastal waters at the punch-out location will create a sediment plume in the nearshore area.

2.2.19 Drilling fluid or drilling mud is a suspension of mainly bentonite clay in water, with the following functions:

- to remove cuttings from in front of the drill bit;
- power the mud motor;
- to transport cuttings from the drill face through the annular space towards the surface;
- lubricate the drill string during drilling phases and any conduit liners or cables during pull back;

- cooling the reamers (cutting tools);
- hole stabilisation; and
- creation of a filter cake against the wall of the hole to minimise the risk of loss of drilling fluid or influx of groundwater penetration into the borehole.

2.2.20 The drilling fluid typically consists of a low concentration bentonite – water mixture. Depending on the formation to be drilled through, the concentration is typically between 30 kg and 100 kg of dry bentonite clay per m³ of water (30,000 to 100,000 mg/l).

2.2.21 The use of bentonite has several benefits:

- it is a natural material;
- it is recyclable;
- it is on the poses little or no risk to the environment (PLONOR) list, so its discharge is not a danger to the environment; and
- owing to the large diameter pipe and long length, the total volume of fluid used may be relatively large, but, owing to the low concentration, the total amount of bentonite is limited.

2.2.22 Based on the range of expected duct lengths (755 m) and maximum diameter (2.2 m), the maximum volume of drilling mud (and other drill cuttings) contained in one conduit is estimated to be up to 2,870 m³. Several stages of drilling (pilot hole drilling and stages of reaming) may result in smaller release events separated in time. The installation of the duct may result in a larger release of fluid from the conduit (up to the total volume); however, in practice, the fluid present at this stage may have been replaced or otherwise reduced to a concentration lower than required for drilling.

2.2.23 The realistic MDS considered is a release of drilling mud with a conservative representative concentration of 100,000 mg/l, up to the total volume of a single conduit (2,870 m³). Therefore, the mass of Bentonite released per port is calculated as 2,870 m^3 x 100 kg/m^3 = 287,000 kg. It is conservatively assumed the total volume is released gradually over a one-hour period (3,600 s). This gives a rate of release of 287,000 kg/3,600 s = 79.8 kg/s.

2.2.24 All of the disturbed sediment is initially released at 5 m above the local seabed level. And Bentonite is represented within the model by 100% silt sediment type.

2.2.25 Because of the time required to drill and finalise each conduit, it is assumed that the three bentonite releases that will occur during the whole construction period would not happen simultaneously, and with a sufficiently long-time gap between punch out events that no overlapping or cumulative changes to SSC are expected. The punch-out release scenario therefore considers the change caused during the creation of a single borehole.

Sediment Type Assumptions

2.2.26 The assumed sediment type within the Export Cable Corridor is informed by acoustic variations in low-frequency side scan sonar data, collected and analysed by G-Tec during the geophysical survey (G-Tec, 2025b). Analysis of side scan sonar data indicates that the seabed sediment is predominantly composed of sand, with some regions of silty sand and gravelly sand also present. This is corroborated by sediment grab samples provided by BGS (BGS, 2025) collected along the Export Cable Corridor, which are predominately classified as gravelly sand, with a small number of samples identified as sandy gravel. The proportion of each grain size fraction (gravel, coarse sand, medium sand, fine sand and silt) was therefore chosen as 10%, 30%, 30%, 20% and 10%, respectively for plume releases originated from the Export Cable Corridor. A 10% silt content is conservatively assumed in sediment disturbed within the Export Cable Corridor, although a much lower proportion (<2%) is recorded in most BGS grab samples.

2.2.27 Sediment grab samples provided by BGS (BGS, 2025) and measured data analysed by G-Tec (G-Tec, 2025a) within and around the Array Area show the seabed is primarily made up of sand, with some regions of silty sand and gravelly sand. The proportion of each grain size fraction (gravel, coarse sand, medium sand, fine sand and silt) was therefore chosen as 10%, 30%, 30%, 20% and 10%, respectively for plume releases originated from the Array Area, capturing the predominantly sandy nature of the sediment with smaller contributions from gravel and silt fractions. A 10% silt content is conservatively assumed in sediment disturbed within the Array Area, although a much lower proportion (<5%) is recorded in most BGS grab samples.

2.2.28 Sediment grab samples provided by BGS (BGS, 2025) for locations within and close to the Morven North OWF array area are used to define the sediment composition representative of releases from this region.

2.2.29 The proportion of sediment mass in each grain size fraction is accounted for in the number and mass of the individual particles released at each timestep within the models.

2.3 Sediment Plume Model Results

Overview

2.3.1 The following results are provided as figures in Annex A:

- Maps of SSC at the end of sediment disturbance, and one and three days later.
- Maps of instantaneous maximum SSC at any time throughout the model simulation period.
- Timeseries of SSC at a central location in the area of sediment disturbance (centre of the MFE route or at the location of drilling or spoil disposal).

2.3.2 The following results are provided as images in Annex B:

- Maps of settled sediment thickness at the end of the model simulation period.

2.3.3 Results for SSC describe an increase in SSC relative to the ambient naturally occurring condition.

2.3.4 Figure 1.1 shows the Special Protection Areas (SPAs), Marine Protected Areas (MPAs) and Special Areas of Conservation (SACs) within the Physical Processes Study Area. To help identify the potential extent of plume interaction with these areas, SPA, MPA and SAC boundaries have been overlaid on the plume modelling results.

Sediment Plume SSC Results

Plumes From Pre-Lay Trenching, Sandwave Clearance and Drilling (i.e. Extended Release Periods Over Multiple Flood/Ebb Cycles)

2.3.5 Maps of the increase in SSC as a result of pre-lay cable trenching using an MFE (moving near-bed source) are provided by Scenarios 1 and 2 for the Array Area, and Scenarios 9 and 10 for the Export Cable Corridor, for neap and spring tidal conditions in Annex A.

2.3.6 Maps of the increase in SSC as a result of local sandwave clearance using an MFE (static near-bed source) are provided by Scenarios 3 and 4 for the Array Area, Scenarios 11 and 12 for the middle of the Export Cable Corridor, and Scenarios 15 and 16 for the nearshore end of the Export Cable Corridor, for neap and spring tidal conditions in Annex A.

2.3.7 Maps of the increase in SSC as a result of continuous drilling at two neighbouring locations (static surface source) are provided by Scenarios 5 and 6 for the Array Area, for neap and spring tidal conditions in Annex A.

2.3.8 The following summary provides a general description and characterisation of the more detailed results shown in the scenario images listed above. See the individual figures for site and scenario specific details of SSC and plume dimensions.

2.3.9 The plume feature resulting from continuous sediment disturbance activities is characterised as a long, relatively thin plume extending downstream from the point of active disturbance. Where the source is moving in the pre-lay trenching scenarios, the path of active disturbance in the simulation period is visible in the results images as a line of higher maximum instantaneous SSC, with elevated SSC regions extending from this aligned with the tidal axis.

2.3.10 The combined SSC from all sediment types is expected to be very high within 5 m of the release location during active sediment disturbance (millions of mg/l within 5 m of the activity, (i.e. more sediment than water in the local plume)). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of 1,000 to 10,000 mg/l. This initial elevated SSC effect is highly localised and will persist only while the disturbance continues in that specific area. As the sediment plume settles and disperses both vertically and horizontally over time and distance downstream, the SSC is anticipated to decrease to less than 1,000 mg/l within tens of metres.

2.3.11 Gravels and sands will settle relatively quickly to the seabed (Table 2.1). At a representative higher current speed of ~0.6 m/s during spring tides, these sediment types will settle from the maximum anticipated height of initial suspension (3 m above the bed) to the seabed within the following approximate distances from the release point: 4 m for gravels, 18 m for coarse sand, 60 m for medium sand, and 180 m for finer sands. This distance will be proportionally reduced during periods of lower current speed, such as times outside peak flow and generally around neap tides.

2.3.12 During spring tidal conditions, the disturbed sediment is carried away from the working area at a faster rate, dispersing the sediment mass over a larger area and water volume, and so the resulting SSC in the plume is relatively lower than on a comparable neap tide.

2.3.13 During slack water (on both neap and spring tides), water is not moving sediment away from the area of disturbance, resulting in suspended sediment accumulating in a local area of relatively higher SSC. This local area of higher SSC is subsequently advected by the tide and may take longer to reduce to background levels than other parts of the plume generated during non-slack water conditions.

2.3.14 The extended release scenarios (pre-lay trenching, sandwave clearance (MFE) and drilling) all exhibit the same general plume characteristics discussed here, but the SSC and size of the plume scales with the sediment release rate used to characterise each disturbance mechanism.

2.3.15 For all release scenarios discussed in this section (Scenarios 1-6, 9-12 and 15-16), SSC is less than 5 mg/l everywhere three days after the disturbance has ended.

2.3.16 Sediment released by pre-lay trenching, sandwave clearance and drilling activities at the southern boundary of the Array Area has the potential to reach the Firth of Forth Banks Complex MPA, when the release period coincides with spring tides. Higher current velocities during spring tides, compared to neap tides, result in the plume traveling further, reaching the designated areas. However, the plume is spatially constrained with limited width/footprint and only just reaches the designated area. This means only a small proportion of the designated areas would potentially be affected by the increase in SSC for a limited duration. The path followed by the tidal ellipse is also not the same on every tide, therefore it is unlikely that the same area of seabed will be affected by elevated SSC within the localised plume for more than one or two consecutive tides. Also, as the MPA is approximately 6.7 km from the closest point in the Array Area, the plume SSC will be already greatly reduced due to re-settlement of sediment, by the time it is advected into the designated area. A maximum instantaneous SSC of <10 mg/l is predicted within the MPA. One day after the release has ended, the plume has been further dispersed and no elevated SSC is predicted within the MPA.

2.3.17 During large spring tides, plumes generated by sandwave clearance in the nearshore region of the Export Cable Corridor have the potential to cause elevated SSC within the Fowlsheugh SPA. However, given the distance of the SPA from the Export Cable Corridor (5.8 km), the spatially constrained nature of the plume, and the variability in the tidal ellipse. This impact will be highly localised, short-lived, and small in magnitude (SSC within the SPA < 10 mg/l).

2.3.18 Plumes generated by pre-lay trenching, sandwave clearance and drilling activities within the offshore region of the Export Cable Corridor do not reach, or directly impact, any designated areas.

Plumes From Spoil Disposal

2.3.19 Maps of the increase in SSC as a result of spoil disposal at the water surface from a Trailing Suction Hopper Dredger (TSHD) are provided by Scenarios 7 and 8 for the Array Area, Scenarios 13 and 14 for the central Export Cable Corridor, and Scenarios 17 and 18 for nearshore areas close to the Landfall, for neap and spring tidal conditions, respectively, in Annex A.

2.3.20 The following summary provides a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures for site and scenario-specific details of SSC and plume dimensions.

2.3.21 The passive phase plume feature (defined previously in Paragraph 2.2.16) resulting from a spoil disposal event is characterised by an ellipsoidal plume, where elevated SSC closely follows the path of the tidal ellipse with higher concentrations towards the release location, and decreasing concentration with increasing time and distance.

2.3.22 Gravels and sands will settle relatively quickly towards the seabed (Table 2.1). From the maximum expected height of initial suspension (approximately 65 m above the bed within the Array Area), these sediments are likely to resettle on the seabed, ceasing to increase SSC, within approximately 2 to 40 minutes. At a representative higher current speed of 0.6 m/s during spring tides, these sediments will settle to the bed within approximately 78 m for gravel, 390 m for coarse sand, 1,300 m for medium sand, and 3,900 m for finer sands from the release point. This distance will be proportionally shorter during periods of lower current speed, such as outside peak flow times and generally around neap tides. Fine sand and silt-sized sediments persist in suspension for longer than relatively coarser sediment grain sizes (i.e. medium sand, coarse sand and gravels) and so control the majority of the effect on SSC beyond these durations/distances.

2.3.23 The level of SSC associated with all sediment fractions is expected to be locally very high at the location of the spoil release (millions of mg/l within 5 m of the activity (i.e. more sediment than water in the local plume). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of 1,000 to 10,000 mg/l.

2.3.24 Due to ongoing dispersion and the settlement of non-silt sediment to the seabed during the first half tidal cycle, the level of SSC within the spoil plume reduces rapidly with time to less than 5 mg/l after one day, and to less than 2 mg/l after 3 days.

2.3.25 Plumes generated by spoil disposal within the Array Area and Export Cable Corridor do not reach, or directly impact, any designated areas.

Plumes From Bentonite Release

2.3.26 Maps of the increase in SSC as a result of Landfall punch out via trenchless techniques (*e.g.* HDD) drilling mud release are provided by Scenarios 19 and 20 for the nearshore area for neap and spring tidal conditions in Annex A.

2.3.27 The following summary provides a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures for site and scenario specific details of SSC and plume dimensions.

2.3.28 At temporal and spatial scales smaller than that captured by the model resolution, the initial plume will have a very high local SSC of bentonite (up to the concentration of the drilling fluid itself) but will have a correspondingly small footprint (hundreds of thousands of mg/l within 5 m of the activity). This level of detail is not resolved directly by the sediment plume model, which indicates a more dispersed initial concentration of >1,000 mg/l. The plume is subsequently advected in the general direction, and at the speed of, the ambient currents at the time of the release, and gradually becomes dispersed, both horizontally and vertically, by the natural process of diffusion.

2.3.29 Due to the small particle size and low settling velocities (Table 2.1), all of the bentonite released is held in suspension for days or longer before settling. In this time, the individual grains become dispersed widely over large areas, meaning SSC reduces to <5 mg/l everywhere within one day of the release.

2.3.30 The bentonite plume does not reach, or directly impact, any designated areas.

Seabed Sediment Deposition Results

Bed Level Changes Associated with Plumes from MFE

2.3.31 Estimates of the footprint and thickness of sediment deposition from MFE trenching are provided based on:

- the results of the sediment plume model; and
- near-field spreadsheet model estimates (for all sediment types).

2.3.32 The sediment plume model results provide a more reliable description of settlement thickness in the far-field (i.e. for sediments that are subject to advection and dispersion over timescales greater than 1 hour and distances greater than 1,000 m).

2.3.33 The near-field spreadsheet model provides a more generalised but demonstrably realistic range of potential deposition area/thickness combination estimates in the near-field, i.e. for sediment of any type that is deposited more rapidly to the seabed in timescales less than 1 hour and distances less than 1,000 m. Such estimates can provide a more reliable description of details in the near-field that are not resolved spatially or temporally by the sediment plume model.

Far-field Plume Model Estimates

2.3.34 Maps of settlement thickness as a result of pre-lay cable trenching using an MFE are provided by Scenarios 1 and 2 for the Array Area, and Scenarios 9 and 10 for the Export Cable Corridor, for neap and spring tidal conditions, respectively, in Annex B.

2.3.35 Maps of settlement thickness as a result of localised sandwave clearance using an MFE are provided by Scenarios 3 and 4 for the Array Area, Scenarios 11 and 12 for the middle of the Export Cable Corridor, and Scenarios 15 and 16 for the nearshore end of the Export Cable Corridor, for neap and spring tidal conditions, respectively, in Annex B.

2.3.36 The following summary provides a general description and characterisation of the more detailed results for each location shown in the figures listed above. See the individual figures for site and scenario-specific details of settlement thickness and extent.

2.3.37 The results show the thickness of sediment following initial deposition. The same sediment may be subsequently re-eroded and resettled elsewhere as part of the ongoing natural sediment transport regime.

2.3.38 The predicted thickness of settlement is limited. The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from seconds up to 5 minutes, i.e. within the 10 minute timestep of the sediment plume model) and so tend to be deposited within a relatively small footprint (from metres up to 200 m), resulting in a relatively greater local average thickness of <500 mm during spring tides in the Array Area and Export Cable Corridor; and <800 mm during neap tides. The predicted thickness of settlement for only the finer sediments is very limited, in the order of <2 mm for all release locations.

2.3.39 Sediment accumulation of this magnitude would not cause a measurable change in bed level or sediment type in practice, particularly considering the mobile nature of the seabed under baseline conditions. Fine sediments that do settle are also likely to experience further erosion and dispersion during subsequent tides. There is no deposition due to MFE releases predicted within any of the surrounding designated areas.

Near-field Spreadsheet Model Estimates

2.3.40 Coarser sediments (gravels and sands) will settle from the maximum height of disturbance (3 m above the bed) relatively rapidly towards the seabed and so the distance of advection and dispersion is realistically limited to distances within 4 m (gravel) to 200 m (finer sands) downstream from the trench during representative stronger tidal current conditions (0.6 m/s). Distances will be proportionally less at times of lower current speed. The plume model does not resolve spatial details less than the resolution of the model mesh (<150 m) and tidal current speed varies widely over flood and ebb, and spring and neap cycles. The following method provides a range of realistic estimates of deposition thickness within the near-field.

2.3.41 The volume of sediment displaced from the trench is finite and proportional to the trench cross section (up to 6 m^2) and so it is possible to estimate the maximum average sediment thickness for a range of realistic downstream dispersion distances. Results are presented in Table 2.3. This calculation conservatively assumes that 100% of the material in the trench is fluidised and displaced, with the downstream dispersion occurring perpendicular to the trench axis. Where the current direction is more oblique to the trench, the perpendicular distance from the trench to the edge of the deposit might be reduced, with a proportional increase in average thickness. In all cases, a larger footprint or extent of effect for any reason will result in a proportionally smaller average thickness of deposition, and *vice versa*.

Table 2.3: Maximum Average Sediment Deposit Thickness for a Range of Realistic Downstream Dispersion Distances

Downstream Dispersion Distance (m)	**Maximum Average Thickness of Sediment Accumulation (mm) for Varying Trench Cross Sections**		
	4 m^2	**5 m^2**	**6 m^2**
5	800	1,000	1,200
10	400	500	600
25	160	200	240
50	80	100	120
100	40	50	60
150	27	33	40
200	20	25	30
250	16	20	24
300	13	17	20

Bed Level Changes Associated with Plumes from Spoil Disposal

2.3.42 Estimates of the footprint and thickness of sediment deposition from dredge spoil disposal are provided based on:

- Sediment plume model predictions for the passive phase of the plume only;
- Near-field spreadsheet model estimates for the passive phase of the plume only (for all sediment types); and
- Near-field spreadsheet model estimates for the active phase of the plume only (for all sediment types).

2.3.43 The sediment plume model results provide a more reliable description of settlement thickness in the far-field, i.e. for sediments that are subject to advection and dispersion over timescales greater than 1 hour and distances greater than 500 m to 1,000 m.

2.3.44 The near-field spreadsheet plume model provides a more generalised but demonstrably realistic range of potential deposition area/thickness combination estimates in the near-field, (i.e. for sediment of any type that is deposited more rapidly to the seabed in timescales less than 1 hour and distances less than 1,000 m). Such estimates provide a more reliable description of details in the near-field that are not resolved spatially or temporally by the sediment plume model.

2.3.45 The results from the plume model relate only to the sediment in the passive phase of the plume (i.e. 10% of the total sediment volume/mass being deposited). Results for the passive and active phases of the plume should be considered together in order to describe the full effect of the dredge spoil release.

Passive Phase – Far-field Plume Model Estimates

2.3.46 Maps of settlement thickness resulting from the passive phase of the plume (~10% of the sediment volume) during dredge spoil disposal are provided by Scenarios 7 and 8 for the Array Area, Scenarios 13 and 14 for the Export Cable Corridor, and Scenarios 17 and 18 for the nearshore region of the Export Cable Corridor, for neap and spring tidal conditions, respectively, in Annex B. The settlement thickness resulting from the active phase of the plume (~90% of the sediment volume) is considered separately in another section below.

2.3.47 The following summary provides a general description and characterisation of the more detailed results for each location and activity shown in the figures. See the individual figures for site and scenario-specific details of settlement thickness and extent.

2.3.48 The results show the thickness of sediment following initial deposition. The same sediment is expected to immediately rejoin the natural sedimentary environment and will be subsequently re-eroded and resettled elsewhere as part of the ongoing natural sediment transport regime.

2.3.49 The predicted thickness of settlement accounting for all sediment types in the passive phase plume is limited. The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from minutes to 1 hour) and so tend to be deposited within a relatively small footprint. In the Array Area the deposit is highly constrained, remaining within 4 km of the release location. The maximum deposited thickness is 25 mm. In the Export Cable Corridor, the deposit is within 5 km of the release location, with a maximum thickness of 20 mm. Nearshore the deposit remains within 2 km of the release location, a maximum deposited thickness of ~40 mm is predicted. The predicted average thickness of settlement for the finer sediments in the passive phase plume is dispersed more widely and the magnitude of deposition is very limited, in the order of <2 mm in all sites.

2.3.50 During spring tides, due to higher current speeds the deposits are dispersed more between the surface and the seabed, typically forming larger footprint deposits with proportionally smaller average local thickness.

2.3.51 Sediment accumulation of this magnitude would not cause a measurable change in bed level or sediment type in practice, particularly considering the mobile nature of the seabed under baseline conditions. Fine sediments that do settle are also likely to experience further erosion and dispersion during subsequent tides. There is no deposition due to MFE releases predicted within any of the surrounding designated areas.

Passive Phase – Near-field Spreadsheet Model Estimates

2.3.52 Coarser sediments (gravels and sands) in the passive plume will settle from the water surface (65 m (mean water depth) above the seabed in the Array Area) relatively rapidly towards the seabed and so the distance of advection and dispersion is realistically limited to distances within 80 m (gravel) to ~4,000 m (finer sands) downstream from the disposal site during representative stronger tidal current conditions (0.6 m/s on spring tides). Distances will be proportionally less at times of lower current speed (and during neap tides). The plume model does not resolve spatial details less than the resolution of the model mesh (~150 m) and tidal current speed varies widely over flood and ebb, and spring and neap cycles. The following method provides a range of realistic estimates for sediment thickness in the near-field.

2.3.53 The total volume of sediment in the passive phase of the plume is limited (10% of 11,000 m^3 = 1,100 m^3) and so it is possible to estimate the maximum average sediment thickness for a range of realistic dispersion footprint dimensions. Results are presented in Table 2.4. These estimates conservatively assume that all sediment in the passive phase is deposited to the seabed, however, the silt fraction (comprising up to 10% of the sediment mass in the passive phase, depending on the location, see Table 2.2) will remain in suspension for longer (as described by the plume model results above) and will not contribute to these estimates.

Table 2.4: Maximum Average Sediment Deposit Thickness as a Result of the Passive Plume for a Range of Realistic Downstream Dispersion Distances

Downstream Dispersion Distance (m)	Maximum Average Thickness of Sediment Accumulation (mm) for Varying Dispersion Widths.		
	50 m	100 m	200 m
100	220	110	55
250	88	44	22
500	44	22	11
750	29	15	7
1,000	22	11	6
2,000	11	6	3
3,000	7	4	2
4,000	6	3	1
5,000	4	2	1

Active Phase – Near-field Spreadsheet Model Estimates

2.3.54 The active phase of the plume will descend rapidly and directly to the seabed, where it will spread laterally, initially with the force of impact and then under gravity. The final shape or dimensions of the deposit therefore cannot be predicted in detail. The volume of sediment in the active phase of the plume is also limited (90% of 11,000 m^3 = 9,900 m^3) and so it is also possible to estimate the maximum average sediment thickness for a range of realistic dispersion footprint areas. Results are presented in Table 2.5.

Table 2.5: Maximum Average Sediment Deposit Thickness for a Range of Realistic Active Phase Deposit Dimensions and Areas

Deposit Length Scale (m)	Deposit Footprint Area (m^2)*	Maximum Average Thickness of Sediment Accumulation (mm)
50	2,500	3,960
100	10,000	990
150	22,500	440
200	40,000	248
222	49,500	200
315	99,000	100
445	198,000	50

*Deposit footprint area = Deposit length scale^2

Bed Level Changes Associated with Plumes from Bentonite Release

2.3.55 Due to the small particle size and low settling velocities (Table 2.1), most of the bentonite released is held in suspension for days or longer before settling. In this time, the individual grains become dispersed widely over large areas, and so does not result in any measurable thickness of bentonite deposition.

2.3.56 Sediment deposition thickness across the Physical Processes Study Area is predicted to be <5 mm in all release cases, which is not measurable in practice and will be, at most, comparable to normally occurring patterns as a result of natural processes and other vessel movement related disturbances.

Tidal Excursion Distance and Plume Advection

2.3.57 The tidal excursion distance is the approximate distance over which a package of water (or a section of plume with elevated SSC) is advected during one flood or ebb tide.

2.3.58 The local extent of the sediment plume at any given time describes the instantaneous local magnitude and extent of elevated SSC. The plume is being almost continuously moved (advected) by the ambient currents. This section considers the distances and directions that the plume might be displaced from the source before it is dissipated to near background concentrations, and therefore the overall spatial extent that any local plume effects might be (temporarily) experienced.

2.3.59 The sediment plume is mainly advected from the source of the sediment disturbance by the ambient tidal currents. The relative motion (local speed and direction) of the plume at any given time in the tidal cycle will vary depending not only on the relative time in the flood ebb cycle, but also the spatially varying flow characteristics along the path of advection.

2.3.60 In open water, plume advection typically describes an elliptical path, which may or may not be closed, (i.e. returning to approximately the same position at the end of the tidal cycle). In areas of more complex flow, the path may be more complex (e.g. following coastline or bathymetric features) and the path may not be necessarily closed. The distance that the plume is advected from the disturbance source (both along the tidal axis and laterally across it) describes the area over which any effects on SSC are likely to occur. Conversely, areas beyond the tidal excursion distance and footprint are unlikely to experience any effect on SSC from the plume.

2.3.61 A summary map of idealised tidal excursion ellipses is shown in Figure 2.1.

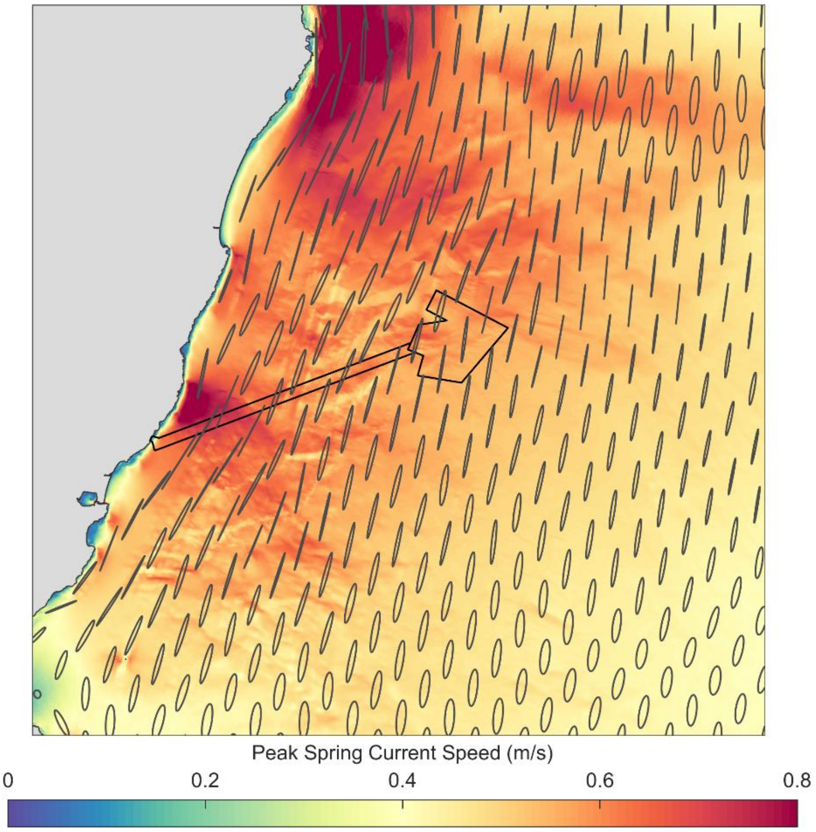

Figure 2.1: Peak Current Speed on a Mean Spring Tide and Associated Tidal Excursion Ellipses

2.3.62 The tidal axis is indicated by the orientation of the long axis of the ellipse. The tidal axis is generally parallel to the adjacent coastlines in offshore areas but varies closer to headlands and estuaries. Across The Proposed Development, the ellipses are relatively long and thin, suggesting a rectilinear pattern of tidal currents (well defined ebb and flood directions with minimal rotation of the tide through the tidal cycle). In practice, patterns of tidal flow are complex, and the path taken by water will be affected by detailed patterns of flow over distances less than one (idealised) tidal excursion in some areas.

2.3.63 The displacement of the plume features by tidal currents also provides a proxy measure of the tidal excursion distance from each of the release locations for representative neap and spring range conditions. The path of the plume (including changes in flow speed and direction elsewhere in the model domain) provides a 'Lagrangian' estimate. In areas of more complex flow (e.g. near to headlands and estuaries), this can provide a more realistic measure than the alternative 'Eularian' estimate (based on the net displacement of water past a particular location).

2.3.64 The tidal excursion distance is the approximate distance over which a package of water (or a section of plume with elevated SSC) is advected during one flood or ebb tide.

2.3.65 The values below were determined based on the observed advection of the plume features in the sediment plume model results, over multiple flood and ebb cycles, during representative mean neap and mean spring tidal range conditions. There can be variation in the peak current speed between consecutive flood and ebb tides, therefore, a small range of tidal excursion distances are presented for tidal ranges representative of mean neap and mean spring conditions.

2.3.66 The tidal excursion distance varies in proportion to the peak current speed during particular flood or ebb cycles. As such, the distance may also be smaller than the mean neap conditions (on smaller than mean neap tidal ranges) and occasionally larger than the mean spring condition (on larger than mean spring tidal ranges).

2.3.67 In the Array Area:

- On neap tides, the tidal excursion distance is ~5 km to 7 km, depending on the peak flow speed during that half tidal cycle.
- On spring tides, the tidal excursion distance is ~9 km to 11 km, depending on the peak flow speed during that half tidal cycle.

2.3.68 In the middle part of the Export Cable Corridor:

- On neap tides, the tidal excursion distance is ~5 km to 7 km, depending on the peak flow speed during that half tidal cycle.
- On spring tides, the tidal excursion distance is approximately 9 km to 11 km, depending on the peak flow speed during that half tidal cycle.

2.3.69 In the nearshore area close to the Landfall of the Export Cable Corridor:

- On neap tides, the tidal excursion distance is ~5 km to 6 km.
- On spring tides, the tidal excursion distance is ~6 km to 8 km.

2.3.70 The spatial variation in Lagrangian tidal excursion provides a more generalised basis for the description of the extent of potential effect on SSC and sediment deposition.

Potential Cumulative Interaction

Suspended Sediment Concentration

2.3.71 Maps of the increase in SSC as a result of sandwave clearance using an MFE are provided by Scenarios 21 and 22 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex A.

2.3.72 Maps of the increase in SSC as a result of drilling are provided by Scenarios 23 and 24 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex A.

2.3.73 Maps of the increase in SSC as a result of spoil disposal are provided by Scenarios 25 and 26 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex A.

2.3.74 Meaningful sediment plume interaction generally only has the potential to occur if the activities generating the sediment plumes are located within one spring tidal excursion ellipse from one another and occur at the same time.

2.3.75 Aligned with the tidal ellipse, which runs approximately south south-west to north north-east, the Morven North array area is located approximately 16 km to the south of the Bowdun Array Area. The distance between the two array areas is large, greater than the extent of the spring tidal excursion ellipse.

2.3.76 The modelled scenarios show the limited spatial footprint and transient nature of the plumes created from disturbance activities in these individual locations. This therefore suggests any cumulative impacts are unlikely and will be of low magnitude and short duration if they do occur. There are no designated areas located in the potential area of cumulative influence between releases originating from the Morven North and Bowdun array areas.

Seabed Sediment Deposition

2.3.77 Maps of settlement thickness as a result of sandwave clearance using an MFE are provided by Scenarios 21 and 22 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex B.

2.3.78 Maps of settlement thickness as a result of drilling are provided by Scenarios 23 and 24 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex B.

2.3.79 Maps of settlement thickness as a result of spoil disposal are provided by Scenarios 25 and 26 for the Morven North array area, for neap and spring tidal conditions, respectively, in Annex B.

2.3.80 There are no overlapping areas of deposition between the Morven North array area releases and the Bowdun releases.

2.4 Sediment Disturbance Conclusions

2.4.1 The numerical modelling approach delivers a detailed analysis of SSC and sediment deposition patterns, complemented by conservative estimations of the near-field deposition using spreadsheet-based methods.

2.4.2 Plumes are characterised as spatially constrained and transient, aligned with the tidal axis. A rectilinear pattern of tidal currents is observed across the Proposed Development, resulting in sediment plumes being dispersed and advected more linearly, approximately parallel to the coastline.

2.4.3 The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from seconds up to 5 minutes) and so tend to be deposited within a relatively small footprint (from metres up to 200 m), resulting in a relatively greater local average thickness of <500 mm during spring tides in the Array Area and Export Cable Corridor; and <800 mm during neap tides. The predicted deposition for the finer sediments is dispersed, resulting in small average thicknesses, in the order of <5 mm over the affected area.

2.4.4 Cumulative impacts from other activities, such as other wind farm construction projects, are expected to be limited. Meaningful plume interaction can only occur if activities are located within the same spring tidal excursion ellipse and occur simultaneously. Given the limited footprint and transient nature of the individual plumes, any cumulative effects, if any, are expected to be small and short-lived.

2.4.5 The findings confirm that the changes in SSC and deposition within designated areas of seabed are limited. Notably, the predicted changes in SSC and sediment deposition are largely confined to the vicinity of construction activities, with minimal overlap into designated areas.

3 Changes to the Wave Regime

3.1 Overview

3.1.1 This section sets out the assessment of changes to the wave regime within the study area, based on spectral wave modelling of the MDS (Volume 2, Chapter 7: Physical Processes) for blockage within the Array Area.

3.1.2 The wave model has been built using the MIKE21FM Spectral Wave (SW) module, which simulates the development, propagation and dispersion of wave energy throughout the model domain.

3.1.3 More detailed information about the design and validation of the wave model may be found in Volume 3, Technical Appendix 7.2: Physical Processes Model Design and Validation.

3.1.4 The wave model creates discrete simulations of significant wave height (Hs), peak wave period (Tp) and mean wave direction (DirM) throughout the domain, for a representative range of selected everyday and extreme wave conditions (return periods and directions). The wave condition scenarios considered by the model for the assessment are:

- Wave coming directions (south south-east (SSE), south-east (SE), east south-east (ESE), east (E) and north (N)); and
- Return periods (RP) (50% non-exceedance, 0.1 yr; 1 yr; 10 yr; 50 yr; 100 yr).

3.1.5 The details of each wave condition modelled are presented in Table 3.1.

Table 3.1: Wave and Wind Boundary Conditions for Each of the Directional Return Period Seastate Conditions Tested

Directional Sector	Case (RP)	Hs (m)	Tp (s)	DirM (°N, from)	Wind Speed @ 10 m (m/s)	Wind Direction (°N, from)
SSE	50% no exc.	1.6	6.5	157.5	8.9	157.5
	0.1 yr RP	5.1	8.6	157.5	17.7	157.5
	1 yr RP	8.2	10.9	157.5	22.7	157.5
	10 yr RP	10.6	12.4	157.5	26.2	157.5
	50 yr RP	11.9	13.2	157.5	27.5	157.5
	100 yr RP	12.4	13.4	157.5	28.2	157.5
SE	50% no exc.	1.4	6.6	135	7.6	135
	0.1 yr RP	4.3	8.3	135	15.4	135
	1 yr RP	6.9	10.6	135	20.0	135
	10 yr RP	9.0	12.0	135	25.0	135
	50 yr RP	10.1	12.8	135	26.8	135
	100 yr RP	10.5	13.0	135	27.0	135

Directional Sector	Case (RP)	Hs (m)	Tp (s)	DirM (°N, from)	Wind Speed @ 10 m (m/s)	Wind Direction (°N, from)
ESE	50% no exc.	1.5	7.3	112.5	7.6	112.5
	0.1 yr RP	5.2	9.4	112.5	15.9	112.5
	1 yr RP	8.4	12.0	112.5	21.2	112.5
	10 yr RP	10.8	13.6	112.5	25.0	112.5
	50 yr RP	12.2	14.4	112.5	27.2	112.5
	100 yr RP	12.7	14.7	112.5	27.8	112.5
E	50% no exc.	1.6	8.0	90	6.7	90
	0.1 yr RP	4.9	9.7	90	16.0	90
	1 yr RP	8.0	12.3	90	21.1	90
	10 yr RP	10.3	14.0	90	24.8	90
	50 yr RP	11.6	14.8	90	26.7	90
	100 yr RP	12.1	15.1	90	27.2	90
N	50% no exc.	1.7	8.8	0	8.3	0
	0.1 yr RP	4.8	9.2	0	16.2	0
	1 yr RP	7.8	11.8	0	21.3	0
	10 yr RP	10.1	13.4	0	24.5	0
	50 yr RP	11.4	14.2	0	26.2	0
	100 yr RP	11.9	14.5	0	27.0	0

3.2 Baseline Conditions

3.2.1 Plots showing the spatial distribution of wave height and direction for each of the baseline wave conditions without any wind farm infrastructure present are shown in Annex C (Figure C1.1 to Figure C1.5).

3.3 Assessment

Bowdun Wind Farm Foundation Type and Number

3.3.1 Volume 1, Chapter 3: Project Description includes a range of Wind Turbine and OSP foundation types, numbers and dimensions. The MDS is identified as the combination of options presenting the greatest total potential blockage to waves passing through the Array Area.

3.3.2 The MDS for Proposed Development is:

- 67 x 15 MW Wind Turbines on 4-legged jacket foundations on pin piles;
  - 4 legs, 3.1 m diameter; and
  - cross bracing, 1.5 m diameter.

- 2 x OSP on piled jacket foundations;
    - 6 legs, 3 m diameter;
    - cross bracing, 1.5 m diameter; and
    - base dimensions at seabed 48 m x 48 m.

3.3.3 Any other combination of foundation type and number would result in a smaller total blockage.

Other Wind Farm Foundation Type and Number

3.3.4 To assess cumulative impacts with neighbouring operational/proposed OWFs (Aberdeen, Kincardine, Seagreen 1, Seagreen 1A, Morven North, Morven South and Ossian), the MDS for wave blockage based on the site-specific Wind Turbine and OSP foundations number and dimensions is estimated for each other OWF.

3.3.5 The MDS for Aberdeen is:

- 11 x Wind Turbines on 3-legged jacket foundations:
    - 3 legs, 1.5 m diameter; and
    - cross bracing, 1 m diameter.

3.3.6 The MDS for Kincardine is:

- 6 x Wind Turbines on semi-submersible floating foundations:
    - 70 m structure width at the surface, with a draft to 20 m below Lowest Astronomical Tide (LAT); and
    - the majority of the substructure is located at the surface, therefore the width of the surface dimension is extended through the whole water column.

3.3.7 The MDS for Seagreen 1 is:

- 114 x Wind Turbines on 4-legged jacket foundations:
    - 4 legs, 3.5 m diameter; and
    - cross bracing, 1.5 m diameter;
- 5 x OSP on 4-legged jacket foundations:
    - 4 legs, 3.5 m diameter; and
    - cross bracing, 1.5 m diameter.

3.3.8 The MDS for Seagreen 1A is:

- 36 x Wind Turbines on 4-legged jacket foundations:
    - 4 legs, 3.5 m diameter; and
    - cross bracing, 1.5 m diameter.

3.3.9 The MDS for Morven North is:

- 96 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 5.1 m diameter; and
  - cross bracing, 1.5 m diameter;
- 6 x OSP on 6-legged jacket foundations:
  - 6 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

3.3.10 The MDS for Morven South is:

- 95 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 5.1 m diameter; and
  - cross bracing, 1.5 m diameter.
- 5 x OSP on 6-legged jacket foundations:
  - 6 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

3.3.11 The MDS for Ossian is:

- 265 x Wind Turbines on semi-submersible floating foundations:
  - 140 m structure width at the surface, with a draft to 40 m below LAT; and
  - the majority of the substructure is located at the surface, therefore the width of the surface dimension is extended through the whole water column.
- 6 x OSP on 12-legged jacket foundations:
  - 12 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

Foundation Layouts

3.3.12 For Bowdun, the foundation layout provided in Volume 1, Chapter 3: Project Description that gives the MDS for wave blockage is for a greater number of smaller Wind Turbines and two OSPs, as shown in Figure 3.1. This layout is realistically representative of any that might be eventually considered.

3.3.13 For Aberdeen, Kincardine, Seagreen 1, Seagreen 1A and Ossian OWFs the foundation locations are determined from site-specific EIA and/or Scoping reports. For Morven North and Morven South, information detailing the specific location of foundations could not be found, therefore a uniform grid layout was assumed to estimate their positions within the Morven North and Morven South Array Areas, these are grouped under a single ‘Morven’ label in the figure below, Similarly, the Seagreen 1 and Seagreen 1A projects are grouped under a single ‘Seagreen’ label in the figure below.

3.3.14 Foundation locations included in the model runs are shown in Figure 3.1.

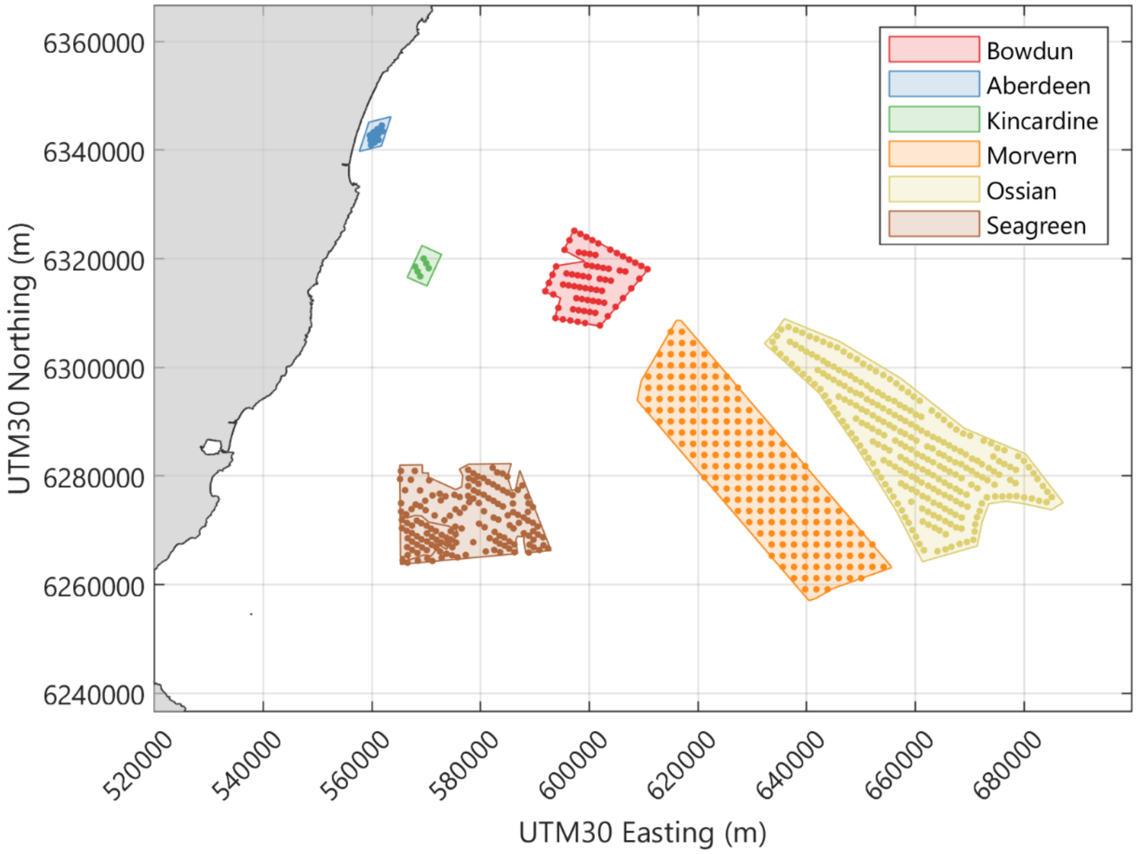

Figure 3.1: Layout of Bowdun Foundations for Physical Processes MDS, and the Estimated Location of Foundations in Other OWFs

Changes to the Wave Regime

Bowdun Only

3.3.15 Plots showing the spatial distribution of changes to wave height for each of the baseline wave conditions as a result of MDS foundation type, number and layout for the Proposed Development are shown in Annex C (Figure C1.6 to Figure C1.10).

3.3.16 Changes less than 5% of the baseline wave height would be indistinguishable from natural variability both within the seastate (difference between individual waves) and compared to normal rates of change (over timescales of one hour or less); such small differences would not be measurable in practice. Changes less than 2.5% are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

3.3.17 The images show that, due to interaction with consecutive foundations, wave height progressively decreases with distance through the Array Area measured in the direction that the waves are travelling. As a result, the maximum reduction in wave height is found downwind of individual Wind Turbines in the central downwind part of the Array Area (7.5% to 10%). The maximum reduction outside of the Array Area in the full range of wave directions and return periods considered is <5%.

3.3.18 The scale of the change is dependent on the nature of the wave height/period condition, and the main direction of the wave energy with respect to the shape/thickness of the array and the alignment of the foundations. The maximum corresponding changes to wave period and wave direction (not shown) are less than 0.1 s and 3 degrees respectively, at all locations, in all cases.

3.3.19 Wave height begins to recover immediately downwind of the Array Area. Recovery occurs mainly due to lateral wave energy spreading from areas to the side of the Array Area where waves are less or completely unaffected by interaction with the wind farm. For smaller seastates, recovery of the dominant wave condition can also occur more rapidly as a result of ongoing wind energy input.

3.3.20 In the area where changes to wave height are greatest (within the Array Area, immediately down-wind of foundation structures), water depths are also relatively large (~65 m below LAT). In such water depths, a minimum wave period (approximately 9 s and larger in 65 m depth) is required to penetrate deeply enough to cause any water movement at the seabed. Even longer waves in conjunction with a sufficient wave height are needed to cause sufficient motion at the seabed to contribute to sediment transport.

3.3.21 As the wave period will not be affected (by more than 0.1 s), the ability of individual waves to reach the seabed will be unaffected. Where an individual wave is large enough to reach the seabed, the predicted change in wave height (proportional to the resulting amplitude of water movement) is locally only up to 5%. The difference is therefore unlikely to result in a measurably different motion of water. Further west, the water depth progressively decreases towards the coastline and so more/smaller waves may interact with the seabed more strongly and more frequently; however, wave height also recovers rapidly with distance downwind of the Array Area and the relative difference in wave height in these shallower areas is even more limited (less than 2.5%).

3.3.22 Differences in wave height are less than 2.5% in nearshore areas (up to 5 km from the coast) and at the adjacent coastlines. For waves coming from the north, where wave pass through the Array Area before reaching Firth of Forth Banks Complex MPA, no observable difference in wave height is predicted (<2.5%).

3.3.23 Sediment transport by waves alone in deep water results in a to-and-fro motion with minimal net transport. In conjunction with tidal currents, waves increase the overall rate of sediment transport, but the combined net transport rate and direction is largely controlled by the speed and direction of the coincident tidal current.

3.3.24 The differences in wave height, period and direction described above are small in absolute and relative terms and (as a small additional contribution to the tidally dominated transport) could only cause an even smaller change to overall instantaneous sediment transport rates or directions. The differences would not be measurable in practice and are easily within the range of natural variability in wave height from wave to wave, from hour to hour during the passage of a storm, and in the context of seasonal and interannual variation of wave climate.

3.3.25 Further discussion of the results is provided in the impact assessment (Volume 2, Chapter 7: Physical Processes).

Bowdun and Other Offshore Wind Farms

3.3.26 Plots showing the spatial distribution of changes to wave height for each of the baseline wave conditions as a result of MDS foundation type, number and layout for the Proposed Development, alongside existing and planned neighbouring OWFs are shown in Annex C (Figure C1.11 to Figure C1.15).

3.3.27 Changes less than 5% of the baseline wave height would be indistinguishable from natural variability both within the seastate (difference between individual waves) and compared to normal rates of change (over timescales of one hour or less); such small differences would not be measurable in practice. Changes less than 2.5% are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

3.3.28 The images show that, due to interaction with consecutive foundations, wave height progressively decreases with distance through the individual Array Areas measured in the direction that the waves are travelling.

3.3.29 Developments with a large number of floating foundations (e.g. Ossian) have a greater impact on the wave regime, resulting in a greater relative reduction of wave height, effecting a larger spatial area. The contribution of the relatively small number of smaller fixed foundations considered for Bowdun are minimal in comparison to these large floating projects.

3.3.30 Cumulative differences in wave height are less than 5% in nearshore areas (up to 5 km from the coast) and at the adjacent coastlines.

4 Changes to the Tidal Regime

4.1 Overview

4.1.1 This section sets out the assessment of changes to the tidal regime within the Physical Processes Study Area, based on hydrodynamic modelling of the MDS (table in Volume 2, Chapter 7: Physical Processes) for blockage within the Array Area.

4.1.2 The hydrodynamic model has been built using the MIKE21FM Hydrodynamic module, which simulates the development, propagation and dispersion of the tidal wave, and associated movements of water, throughout the model domain.

4.1.3 More detailed information about the design and validation of the hydrodynamic model may be found in Volume 3, Technical Appendix 7.2: Physical Processes Model Design and Validation.

4.1.4 The hydrodynamic model creates a continuous simulation of tidal water level, depth-average current speed and current direction throughout the domain, for a representative spring-neap cycle (approximately mean neap and mean spring conditions) during the model validation period.

4.2 Baseline Conditions

4.2.1 Plots showing the spatial distribution of current speed and direction for representative neap and spring conditions, during low water, peak flood, high water and peak ebb periods, without any wind farm infrastructure present are shown in Annex D (Figure D1.1 and Figure D1.2).

4.3 Assessment

Bowdun Wind Farm Foundation Type and Number

4.3.1 Volume 1, Chapter 3: Project Description includes a range of Wind Turbine and OSP foundation types, numbers and dimensions. The MDS is identified as the combination of options presenting the greatest total potential blockage to waves passing through the Array Area.

4.3.2 The MDS for the Proposed Development is:

- 67 x 15 MW Wind Turbines on 4-legged jacket foundations on pin piles:
  - 4 legs, 3.1 m diameter; and
  - cross bracing, 1.5 m diameter.
- 2 x OSP on piled jacket foundations:
  - 6 legs, 3 m diameter; and
  - cross bracing, 1.5 m diameter.

4.3.3 Any other combination of foundation type and number would result in a smaller total blockage.

Other Wind Farm Foundation Type and Number

4.3.4 To assess cumulative impacts with neighbouring existing/planned OWFs (Aberdeen, Kincardine, Seagreen 1, Seagreen 1A, Morven North, Morven South and Ossian), the MDS for wave blockage based on the site-specific Wind Turbine and OSP foundations number and dimensions is estimated for each other OWF.

4.3.5 The MDS for Aberdeen is:

- 11 x Wind Turbines on 3-legged jacket foundations:
  - 3 legs, 1.5 m diameter; and
  - cross bracing, 1 m diameter.

4.3.6 The MDS for Kincardine is:

- 6 x Wind Turbines on semi-submersible floating foundations:
  - 70 m structure width at the surface, with a draft to 20 m below LAT.

4.3.7 The MDS for Seagreen 1 is:

- 114 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 3.5 m diameter; and
  - cross bracing, 1.5 m diameter.
- 5 x OSP on 4-legged jacket foundations:
  - 4 legs, 3.5 m diameter; and
  - cross bracing, 1.5 m diameter.

4.3.8 The MDS for Seagreen 1A is:

- 36 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 3.5 m diameter; and
  - cross bracing, 1.5 m diameter.

4.3.9 The MDS for Morven North is:

- 96 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 5.1 m diameter; and
  - cross bracing, 1.5 m diameter.
- 6 x OSP on 6-legged jacket foundations:
  - 6 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

4.3.10 The MDS for Morven South is:

- 95 x Wind Turbines on 4-legged jacket foundations:
  - 4 legs, 5.1 m diameter; and
  - cross bracing, 1.5 m diameter.

- 5 x OSP on 6-legged jacket foundations:
  - 6 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

4.3.11 The MDS for Ossian is:

- 265 x Wind Turbines on semi-submersible floating foundations:
  - 140 m structure width at the surface, with a draft to 40 m below LAT.
- 6 x OSP on 12-legged jacket foundations;
  - 12 legs, 5 m diameter; and
  - cross bracing, 1.5 m diameter.

Foundation Layouts

4.3.12 For Bowdun, the foundation layout provided in Volume 1, Chapter 3: Project Description that gives the MDS for wave blockage is for a greater number of smaller Wind Turbines and two OSPs. This layout is realistically representative of any that might be eventually considered.

4.3.13 For Aberdeen, Kincardine, Seagreen 1, Seagreen 1A and Ossian OWFs the foundation locations are determined from site-specific EIA and/or Scoping reports. For Morven North and Morven South, information detailing the specific location of foundations could not be found, therefore a uniform grid layout was assumed to estimate their positions within the Morven North and Morven South Array Areas, these are grouped under a single 'Morven' label in Figure 3.1. Similarly, the Seagreen 1 and Seagreen 1A projects are grouped under a single 'Seagreen' label in the Figure 3.1.

4.3.14 Foundation locations included in the model runs are shown in Figure 3.1.

Changes to the Tidal Regime

4.3.15 Further discussion of the results is also provided in the impact assessment (Volume 2, Chapter 7: Physical Processes).

Instantaneous Current Speed and Direction

Bowdun Only

4.3.16 Plots showing the spatial distribution of changes to current speed for selected tidal conditions as a result of the MDS foundation type, number and layout for Bowdun only, are shown in Annex D (Figure D1.3 and Figure D1.4).

4.3.17 The model has a relatively high spatial resolution of 100 m in the Physical Processes Study Area. The model therefore describes the change caused by the individual foundations, and the propagation and recovery of wake features, at a similar scale. In practice, at a more local sub-grid scale (order of metres), slightly greater changes might be expected in the very local flow field of the individual foundations (e.g. a narrow wake approximately as wide as the foundation, and turbulent eddies in the order of tens of centimetres to a few metres within the wake footprint, all recovering to ambient conditions within the order of tens to a few hundreds of metres downstream).

4.3.18 Changes less than 5% of the baseline condition (approximately 0.15 m spring tidal range, 0.03 m/s current speed or 5° current direction) would be largely indistinguishable from frequent and high natural rates of change over various timescales, including: flood/ebb/slack; spring-neap; solstice-equinox; interannual/metonic cycle; and, variability in response to meteorological (surge) influence. Such small absolute differences would also not be accurately measurable in practice. Changes less than 0.01 m/s are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

4.3.19 The result figures show that changes to current speed at the resolution of the model (at length scales greater than 100 m) will be less than 0.05 m/s (10%), which is very small in both absolute and relative terms. The greatest change, a reduction in current speeds, occurs directly downstream of the foundation structure and is highly localised. This wake signature dissipates and recovers with distance downstream. For the Bowdun Array Area, this becomes less than a 5% reduction within ~300 m of the Wind Turbine foundation structures and within 700 m of OSP foundation structures, which is within the range of natural variability, and not measurable in practice. Other OWF wakes are similarly spatially constrained, therefore no cumulative blockage effects on the tidal regime are observed. Corresponding changes to current direction across the study area (not shown in the figures) are less than 1 degree.

Bowdun and Other Offshore Wind Farms

4.3.20 Plots showing the spatial distribution of changes to current speed for selected tidal conditions as a result of the MDS foundation type, number and layout for Bowdun and other neighbouring existing and planned OWFs, are shown in Annex D Tidal Model Baseline and Results Figures(Figure D1.5 to Figure D1.6).

4.3.21 Changes less than 5% of the baseline condition (approximately 0.11 m spring tidal range, 0.03 m/s current speed or 5° current direction) would be largely indistinguishable from frequent and high natural rates of change over various timescales, including: flood/ebb/slack; spring-neap; solstice-equinox; interannual/metonic cycle; and, variability in response to meteorological (surge) influence. Such small absolute differences would also not be accurately measurable in practice. Changes less than 0.01 m/s are also less than the reasonably expected accuracy of the model and so are excluded from the colour scale.

4.3.22 The result figures show that changes to current speed at the resolution of the model (at length scales greater than 100 m) will be less than 0.05 m/s (10%), which is very small in both absolute and relative terms. A reduction in current speeds occurs directly downstream of the foundation structures. The largest changes in current speed are predicted for the larger floating OWFs (e.g. Ossian).

4.3.23 The changes in current speed are highly localised, with wake signatures dissipating and recovering quickly with distance downstream (<1,000 m). As a result, there is no cumulative interaction between OWFs on tidal currents or direction.

Residual Current Speed and Direction

4.3.24 The timeseries of current speed and direction throughout the model domain was also used to determine the residual current speed and direction (the long-term drift rate and direction of water over one spring-neap cycle).

4.3.25 Consistent with the limited scale of change in instantaneous current speed and direction described above as a result of the MDS foundation type, number and layout for the Bowdun only and Cumulative cases, no measurable change in residual current speed or direction is predicted either within the Array Area, or elsewhere.

4.3.26 A plot showing the spatial distribution of residual current speed and direction is shown in Annex D (Figure D1.7).

Tidally Driven Sediment Transport Rate and Direction

4.3.27 The timeseries of current speed and direction throughout the model domain was also used in conjunction with a simple sediment transport model (using the MIKE21FM Sand Transport (ST) module). The model simulates a time series of total load transport rate and direction for 250 µm diameter quartz sand in response to the shear stress caused by the tidal currents described by the hydrodynamic model.

4.3.28 The model results were used to determine the residual sand transport rate and direction (the long-term transport rate and direction for representative medium to fine sand over one spring-neap cycle). Consistent with the limited scale of change in instantaneous current speed and direction described above for the Bowdun only and Cumulative cases, no measurable change in residual sediment transport is predicted either within the Array Area, or elsewhere.

4.3.29 Localised narrow wake features not resolved by the model may have a similarly localised effect on the texture (but not the morphology) of the seabed within their footprint; the wake is only likely to result in changes to seabed morphology immediately around the foundation base in the form of scour (described in Section 5).

4.3.30 Plots showing the spatial distribution of instantaneous sediment transport rate and direction for selected tidal conditions, and the residual sediment transport rate and direction over a representative spring-neap cycle, are shown in Annex D (Figure D1.8 to Figure D1.10).

5 Scour and Seabed Alteration

5.1 Overview

5.1.1 The purpose of this section is to conservatively and quantifiably estimate the area of seabed that will be altered during the operational phase of the Proposed Development as a result of sediment scour that may develop adjacent to turbine foundations (in the absence of any scour protection).

5.1.2 The term scour refers here to the development of pits, troughs or other depressions in the seabed sediments around the base of turbine foundations. Scour is the result of net sediment removal over time (typically in the order of hours to days from installation in mobile sediments) due to the complex three-dimensional interaction between the foundation and ambient flows (currents and/or waves). Such interactions result in locally accelerated time-mean flow and locally elevated turbulence levels that enhance sediment transport potential in the area of influence. The resulting dimensions of the scour features and their rate of development are, generally, dependent upon the characteristics of the:

- obstacle (dimensions, shape and orientation);
- ambient flow (depth, magnitude, orientation, and variation including tidal currents, waves, or combined conditions); and
- seabed sediment (geotextural and geotechnical properties).

5.1.3 Based on the existing literature and evidence base, an equilibrium depth and pattern of scour can be empirically approximated for given combinations of these parameters. Natural variability in the above parameters means that the predicted equilibrium scour condition may also vary over time on, for example, spring-neap, seasonal or annual timescales. The time required for the equilibrium scour condition to initially develop is also dependent on these parameters and may vary from hours to years.

5.1.4 Scour assessment for EIA purposes is considered here for four foundation types: piled jacket foundations (a 4-legged version); piled jacket foundations (a 3-legged version); suction bucket jacket (a 3-legged version) and monopile foundations. Each foundation type may produce different scour patterns therefore all types with a significant seabed footprint have been considered.

5.1.5 The concerns under consideration include the seabed area that may become modified from its natural state (potentially impacting sensitive receptors through habitat alteration) and the volume and rate of additional sediment resuspension, as a result of scour. The seabed area directly affected by scour may be modified from the baseline (pre-development) or ambient state in several ways, including:

- a different (coarser) surface sediment grain size distribution may develop due to winnowing of finer material by the more energetic flow within the scour pit;
- a different surface character will be present if scour protection (e.g. rock protection) is used;
- seabed slopes may be locally steeper in the scour pit; and
- flow speed and turbulence may be locally elevated.

5.1.6 The magnitude of any change will vary depending upon the foundation type, the local baseline oceanographic and sedimentary environments and the type of scour protection implemented (if needed). In some cases, the modified sediment character within a scour pit may not be so different from the surrounding seabed; however, changes relating to bed slope and elevated flow speed and turbulence close to the foundation are still likely to apply. No direct assessment is offered within this document as to the potential impact on sensitive ecological receptors.

5.1.7 The assessment presented here is not intended for use in detailed engineering design. However, methodologies similar to those recommended for the design of offshore wind foundations (e.g. Det Norske Verita (DNV), 2016) have been used in some cases where they are applicable. The methods applied to assess scour are set out in Annex E.

5.2 Baseline Conditions

5.2.1 Where obstacles are not present on the seabed, normal sediment transport processes can cause spatial and temporal variations in seabed level and sediment character in the baseline environment. Scour is a similar but localised change resulting from particular local patterns of sediment transport. Scour may also occur in the baseline environment in response to natural obstacles such as rocky outcrops or boulders. Key features of the baseline environment pertinent to the assessment of scour due to the presence of wind farm infrastructure are summarised below:

- most of the Array Area is expected to be covered by marine/glacio-marine Quaternary deposits with a thickness of 30 m to 50 m, with the thickest deposition (>50 m) in the north-eastern part of the Array Area;
- surficial sediments are found overlying the Quaternary units but are shown to be thin (0 m to 2 m thick) or absent in many areas;
- the Array Area seabed sediments are predominantly classified as sand, with some regions of silty sand and gravelly sand also present; and
- some areas of scattered boulders exist, these infer glacially derived deposits corresponding to the Marr Bank Formation.

5.3 Evidence Base

5.3.1 This scour assessment is based on a key publication by Whitehouse (1998) that provides a synthesis of a range of research papers, industry reports, monitoring studies and other evidence available at that time, describing the patterns and dimensions of scour that result from a variety of obstacle shapes, sizes and environmental conditions. Building upon a theoretical understanding of the processes involved, the accepted methods for the prediction of scour mainly rely on stochastic relationships and approaches (i.e. relationships that are based on and describe the available evidence). As such, scour analysis is an evidence-based science where suitable analogues provide the most robust basis for prediction.

5.3.2 Since the publication of Whitehouse (1998), evidence continues to be collected, and other predictive relationships have been developed and reported by the research community. In general, more recent observations (e.g. summarised in Deltares, 2023) are consistent with the approaches (and associated ranges of uncertainty) presented in Whitehouse (1998). As the evidence base has grown, additional approaches and relationships have been developed to better predict scour for a wider range of more specific obstacle shapes, sizes and environmental conditions.

5.3.3 Monitoring evidence regarding scour development around unprotected wind farm monopile installations is provided by HR Wallingford *et al.* (2007) and ABPmer *et al.* (2010) in a series of monitoring data synthesis reports for Department for Trade and Industry and Collaborative Offshore Wind Research into the Environment Limited. HR Wallingford *et al.* (2007) note that the available data support the view that scour is a progressive process that can occur where the seabed sediment is potentially erodible and there is an adequate thickness of that sediment for scouring to occur. Where the seabed comprises consolidated pre-Holocene sedimentary units, the scour will be slower to develop and limited in depth. For instance, geotechnical surveys at Kentish Flats OWF (Outer Thames) show that the seabed consists of non-cohesive sands over more resistant London Clay. The post construction monitoring evidence generally indicates that maximum scour rates around the monopiles (of diameter 4.3 m) occurred during the first year from installation and then rapidly slowed with near stability occurring by the third anniversary of the works. Scour depths ranged from 1.5 m to 1.9 m at the monitoring locations and the results indicate that the scour depth is restricted by the cohesive underlying clay formation (TEDA, 2012).

5.3.4 A research paper by Whitehouse *et al.* (2011) provides a summary of the field evidence for scour around gravity base foundations in the North Sea used in oil and gas projects. This review emphasised the sensitivity of scour to foundation shape, with foundations in very close proximity sharing similar hydrodynamic/sedimentary environments displaying markedly different scour characteristics. This review also described field evidence for scour around a rectangular gravity base foundation (75 m by 80 m by 16 m high) located within the North Sea in 42 m water depth. Scour was measured as 2.5 m to 3.5 m deep in 0.15 mm (i.e. fine) sand.

5.3.5 Scour protection is evidently a mature engineering concept and by design will both prevent primary scour and minimise secondary scour. The evidence base supporting the design of scour protection is therefore strong but is not relevant to this assessment. The evidence base concerning the environmental impacts of scour protection is more limited. Although multi-layered gravel and rock scour protection is being successfully used at the Thornton Bank OWF in conjunction with six gravity base foundations in a sandy environment with water depths of 28 m (ABPmer *et al.*, 2010).

5.4 Assessment

Outline of Structures Considered in Assessment

5.4.1 The following foundation structures have been considered within the assessment presented in this section:

- Jacket foundations on pin piles (4-legged):
    - 40 x 25 MW Wind Turbines - 41 m x 41 m base with four 4.3 m diameter legs, on 5 m diameter, 5 m above sea level (ASL) pin piles; and
    - 67 x 15 MW Wind Turbines - 35 m x 35 m base with four 3.1 m diameter legs, on 3.8 m diameter, 5 m ASL pin piles.
- Jacket foundations on pin piles (3-legged):
    - 40 x 25 MW Wind Turbines - 43 m x 43 m base with three 4.5 m diameter legs, on 5 m diameter, 5 m ASL pin piles; and
    - 67 x 15 MW Wind Turbines - 37 m x 37 m base with three 3.3 m diameter legs, on 4.1 m diameter, 5 m ASL pin piles.
- Jacket foundation on suction buckets (3-legged):
    - 40 x 25 MW Wind Turbines - 43 m x 43 m base with three 4.5 m diameter legs, on 19 m diameter, 1.5 m ASL suction buckets; and
    - 67 x 15 MW Wind Turbines - 37 m x 37 m base with three 3.3 m diameter legs, on 17 m diameter, 1.5 m ASL suction buckets.
- Monopile:
    - 40 x 25 MW Wind Turbines – 15 m diameter monopile; and
    - 67 x 15 MW Wind Turbines – 13 m diameter monopile.

5.4.2 For each foundation type, both the largest and smallest structures have been considered. This is because the former has the potential to cause the greatest extent of scour at the scale of individual foundations, whereas the latter may potentially be associated with the greatest extent of scour at the Array Area scale, owing to the larger number of structures.

Factors Affecting Equilibrium Scour Depth

Engineering Controls – Scour Protection

5.4.3 The greatest preventative influence on local scour depth would arise from the installation of scour protection. If correctly designed and installed, scour protection will essentially prevent the development of local primary scour as described in this section. The dimensions and nature of scour protection may vary between designs but given its purpose, would likely cover an area of seabed approximately similar to the predicted extent of the scour.

5.4.4 Interaction between ambient currents and the scour protection may lead to the development of secondary scour at its edges. The local dimensions of secondary scour are highly dependent upon the specific shape, design and placement of the protection. These parameters are highly variable and so there is no clear quantitative method or evidence base for accurately predicting the dimensions of secondary scour. However, as for foundations, the approximate scale of the scour depth and extent is likely to be proportional to the much smaller size of the individual elements comprising the protection.

Natural Controls

5.4.5 As summarised in Whitehouse (1998), a number of factors are known to influence equilibrium scour depth for monopiles, contributing to the range of observed equilibrium scour depths. These factors include the:

- frequency and magnitude of ambient sediment transport;
- ratio of structure diameter to water depth;
- ratio of structure diameter to peak flow speed;
- ratio of structure diameter to sediment grain size;
- sediment grain size, gradation and the geotechnical properties of sedimentary units; and
- the thickness of erodible sediment overlying more erosion resistant sublayers.

5.4.6 The influence of these factors where they do apply is to generally reduce the depth, extent and volume of the predicted scour, hence providing a less conservative estimate. For example, a greater frequency and magnitude of sediment transport can actually reduce the equilibrium scour depth, as the scour hole is also simultaneously being (partially) in-filled by ambient sediment transport.

5.4.7 The above factors have been considered in the context of the Array Area and most (except the thickness of erodible sediment) were not found to significantly or consistently reduce the predicted values for the purposes of EIA. The thickness of unconsolidated (and more easily erodible) surficial Holocene sediment is relatively thin across the Array Area, between 0 m and 2 m thick (G-Tec, 2025a). In practice, this will fundamentally limit maximum potential scour depth in most of the Array Area. The following assessment conservatively assumes that foundations will be located in areas of deeper erodible sediment where the full equilibrium scour depth might eventually occur.

Time for Scour to Develop Around Foundation Options

5.4.8 Scour depth can vary significantly under combined current and wave conditions through time (Harris *et al*., 2010). Monitoring of scour development around monopile foundations in UK OWF sites suggest that the timescale to achieve equilibrium conditions can be of the order of 60 days in environments with a potentially mobile seabed (Harris *et al*., 2011). However, as previously stated, equilibrium scour depths may not be reached for a period of several months or even a few years where erosion resistant sediments/geology are present. These values account for tidal variations as well as the influence of waves. (Near) symmetrical scour will only develop following exposure to both flood and ebb tidal directions.

5.4.9 Under waves or combined waves and currents an equilibrium scour depth for the conditions existing at that time may be achieved over a period of minutes, while typically under tidal flows alone equilibrium scour conditions may take several months to develop.

Spatial Extent of Scour

5.4.10 At the Scroby Sands OWF, narrow, elongated scour features have been observed to extend over tens or hundreds of metres from individual foundations, leading to a more extensive impact than would normally be predicted. The development of elongate scour features at Scroby Sands is considered to have occurred due to the strongly rectilinear nature of the tidal currents (a very well defined tidal current axis with minimal deviation during each half tidal cycle) which allows the narrow turbulent wake behind each foundation to persist over the same areas of seabed for a greater proportion of the time, leading to net erosion in these areas. Due to a relatively higher rate of tidal rotation, the development of such elongate scour features is less likely to occur within the Array Area.

Results

5.4.11 Table 5.1 and Table 5.2 summarise the key results of the first-order scour assessment undertaken using the methodological approach set out in Annex E. Results conservatively assume that maximum equilibrium scour depths are symmetrically present around the perimeter of the structure in a uniform and frequently mobile sedimentary environment. Derivative calculations of scour extent, footprint and volume assume an angle of internal friction = 32°. Scour extent is measured from the structure's edge. Scour footprint excludes the footprint of the structure. Scour pit volumes for jacket foundation structures are calculated as the sum of the volume of an inverted truncated cone, minus the structure volume, for each of the corner piles.

5.4.12 In the following section, the term ‘local scour’ refers to the local response to individual structure members. ‘Global scour’ refers to a region of shallower but potentially more extensive scour associated with a multi-member foundation resulting from the change in flow velocity through the gaps between members of the structure and turbulence shed by the entire structure. Global scour does not imply scour at the scale of the wind farm array area.

Table 5.1: Summary of Predicted Maximum Scour Dimensions for Wind Turbine Foundation Structures

Parameter		Foundation Type							
		4-legged Jacket on Piles (35 m base, 3.1 m diameter)	4-legged Jacket on Piles (41 m base, 4.3 m diameter)	3-legged Jacket on Piles (37 m base, 3.3 m diameter)	3-legged Jacket on Piles (43 m base, 4.5 m diameter)	3-legged Jacket on suction bucket (37 m base, 3.3 m diameter)	3-legged Jacket on suction bucket (43 m base, 4.5 m diameter)	Monopile (13 m diameter)	Monopile (15 m diameter)
Equilibrium Scour Depth* (m)	**Steady current**	4	5.6	4.3	5.9	4.9	6.7	16.9	19.5
	Waves	Insufficient for scour							
	Waves and current	4	5.6	4.3	5.9	4.9	6.7	16.9	19.5
	Global scour	1.24	1.72	1.32	1.8	1.32	1.8	NA	NA
Extent from foundation ** (m)	**Local scour**	6.4	8.9	6.9	9.4	7.9	10.8	27	31.2
	Global scour	35	41	37	43	37	43	NA	NA
Footprint (m^2)**	**Structure alone**	45	79	40	59	681	851	133	177
	Local scour***	831	1,568	710	1,267	1,852	3,020	3,403	4,530
	Global scour***	3,803	5,202	4,261	5,750	3,620	4,958	NA	NA

Parameter		**Foundation Type**							
		4-legged Jacket on Piles (35 m base, 3.1 m diameter)	**4-legged Jacket on Piles (41 m base, 4.3 m diameter)**	**3-legged Jacket on Piles (37 m base, 3.3 m diameter)**	**3-legged Jacket on Piles (43 m base, 4.5 m diameter)**	**3-legged Jacket on suction bucket (37 m base, 3.3 m diameter)**	**3-legged Jacket on suction bucket (43 m base, 4.5 m diameter)**	**Monopile (13 m diameter)**	**Monopile (15 m diameter)**
Volume (m^3)**	**Local scour*****	1,208	3,225	1,093	2,772	1,572	3,986	22,279	34,224
	Global scour (exc. Local scour and structure)	4,716	8,948	5,625	10,350	4,778	8,925	NA	NA

* Results assume erodible bed and absence of geological controls
** Based upon the scour depth for steady currents. Footprint and volume values are per foundation.
*** Excluding structure

Table 5.2: Total Seabed Footprint of the Different Foundation Types With and Without Scour

Parameter	Foundation Type							
	4-legged Jacket on Piles (35 m base, 3.1 m diameter)	4-legged Jacket on Piles (41 m base, 4.3 m diameter)	3-legged Jacket on Piles (37 m base, 3.3 m diameter)	3-legged Jacket on Piles (43 m base, 4.5 m diameter)	3-legged Jacket on suction bucket (37 m base, 3.3 m diameter)	3-legged Jacket on suction bucket (43 m base, 4.5 m diameter)	Monopile (13 m diameter)	Monopile (15 m diameter)
Maximum number of foundations	67 Wind Turbine + 3 OSP	40 Wind Turbine + 3 OSP	67 Wind Turbine + 3 OSP	40 Wind Turbine + 3 OSP	67 Wind Turbine + 3 OSP	40 Wind Turbine + 3 OSP	67 Wind Turbine + 3 OSP	40 Wind Turbine + 3 OSP
Seabed footprint of all foundations (m²)	3,207	3,352	2,872	2,552	45,819	34,232	9,083	7,260
Proportion of Array Area* (%)	0.002	0.002	0.002	0.001	0.025	0.018	0.005	0.004
Seabed footprint of all local scour (m²)	60,570	67,613	52,463	55,573	128,977	125,693	232,894	186,093
Proportion of Array Area* (%)	0.032	0.036	0.028	0.030	0.069	0.067	0.125	0.100
Seabed footprint of all foundations + local scour (m²)	63,777	70,965	55,335	58,125	174,796	159,925	241,977	193,353
Proportion of Array Area* (%)	0.034	0.038	0.030	0.031	0.093	0.086	0.129	0.103
Seabed footprint of all global scour (m²)	276,326	229,605	307,012	251,525	264,065	219,845	NA	NA
Proportion of Array Area* (%)	0.148	0.123	0.164	0.135	0.141	0.118	NA	NA

Parameter	**Foundation Type**							
	4-legged Jacket on Piles (35 m base, 3.1 m diameter)	**4-legged Jacket on Piles (41 m base, 4.3 m diameter)**	**3-legged Jacket on Piles (37 m base, 3.3 m diameter)**	**3-legged Jacket on Piles (43 m base, 4.5 m diameter)**	**3-legged Jacket on suction bucket (37 m base, 3.3 m diameter)**	**3-legged Jacket on suction bucket (43 m base, 4.5 m diameter)**	**Monopile (13 m diameter)**	**Monopile (15 m diameter)**
Seabed footprint of all scour protection (m^2)	189,491	162,880	177,580	144,492	221,100	144,000	222,306	176,720
Proportion of Array Area* (%)	0.101	0.087	0.095	0.077	0.118	0.077	0.119	0.095
Seabed footprint of all foundation + scour protection (m^2)	192,698	166,232	180,452	147,044	266,919	178,232	231,389	183,980
Proportion of Array Area* (%)	0.103	0.089	0.097	0.079	0.143	0.095	0.124	0.098

* Total Array Area = 186.98 km^2

5.4.13 Key findings are summarised below:

- overall, scour development within the Array Area is expected to be dominated by the action of tidal currents;
- in practice, the thickness of unconsolidated (and more easily erodible) surficial Holocene sediment is relatively thin (0 m to 2 m thick), or absent);
- of all the Wind Turbine foundation options under consideration, a 15 m diameter monopile has the potential to cause the greatest equilibrium local scour depth (19.5 m), footprint (4,530 m^2) and volume (up to 34,224 m^3), but only in areas where the seabed is potentially erodible by the action of scour to that depth;
- the greatest individual Wind Turbine foundation global scour footprint is associated with the 3-legged jacket foundation, with 43 m base and 4.5 m diameter legs (5,750 m^2), although with a relatively small average depth (1.8 m);
- for the Array Area as a whole, the greatest total foundation local scour footprint is associated with an array of 67 15 MW Wind Turbine monopile foundations (13 m diameter) and three OSP 4-legged jacket foundations (48 m base, 4.5 m near bed diameter) (232,894 m^2), equivalent to only approximately 0.125% of the total Array Area; and
- for the Array Area as a whole, the greatest total Wind Turbine foundation global scour footprint is associated with an array of 67 15 MW Wind Turbine 3-legged piled jacket foundations (37 m base, 3.3 m diameter legs) and three OSP 4-legged piled jacket foundations (48 m base, 4.5 m near bed diameter) (307,012 m^2), equivalent to only approximately 0.164% of the total Array Area.

6 Summary

6.1.1 The assessments presented in this technical report inform the technical analysis and the assessment of the likely significant environmental effects of the Proposed Development on Physical Processes, including changes to:

- suspended sediment concentration, bed levels and sediment type;
- the wave regime;
- the tidal regime and tidally driven sediment transport; and
- seabed alteration through scour.

6.1.2 This assessment has been informed by a combination of analysis of baseline information and numerical modelling (hydrodynamic, spectral wave and particle tracking) results.

6.1.3 Particle tracking modelling results, alongside conservative spreadsheet-based methods allow an analysis of the local extent, duration and magnitude of change to SSC, and sediment deposition patterns, as the result of activities causing sediment disturbance. Sediment plumes released across the Proposed Development are characterised as spatially constrained and transient, aligned with the tidal axis. The coarser sand and gravel fractions at each site settle to the seabed within a limited time of release (from seconds up to 5 minutes) and so tend to be deposited within a relatively small footprint (from metres up to 200 m from the activity site), resulting in a locally measurable settled sediment layer (average thickness <800 mm and <500 mm during neap and spring tide conditions, respectively). Finer sediments will remain in suspension for longer, becoming relatively more dispersed over time, resulting in a locally limited or an immeasurable thickness settled sediment layer (in the order of <5 mm, but potentially over a larger area). Cumulative plume impacts with/from other activities, such as other wind farm construction projects, are also shown to be limited due to relative alignment and distance. The predicted effect of plumes (measurable changes in SSC and sediment deposition) are largely confined to the near vicinity of construction activities, with minimal overlap into designated conservation areas.

6.1.4 Spectral wave modelling allows an analysis of the effect of the Proposed Development (alone and cumulatively with neighbouring OWFs) on the wave regime. Model results show that wave height (a measure of wave energy) progressively decreases with distance of travel through the Array Area, due to the cumulative local blockage effect of the individual foundations. As a result, the maximum reduction in wave height is found downwind of individual Wind Turbines in the central downwind part of the Array Area (7.5% to 10%). The maximum corresponding changes to wave period and wave direction of the seastates tested are less than 0.1 s and 3° respectively. Wave height begins to naturally recover (through lateral spreading of wave energy, and ongoing wind energy input) immediately downwind of the Array Area, meaning the magnitude of change progressively decreases (recovers towards baseline conditions) with distance downwind of the Array Area. The maximum reduction outside of the

Array Area in the full range of wave directions and return periods considered is <5%.

6.1.5 The differences in wave height, period and direction due to the presence of the Proposed Development are shown to be small in absolute and relative terms and could only cause a correspondingly small change in the contribution of wave action to overall instantaneous sediment transport rates or directions (normally dominated by tidal processes). The differences would not be measurable in practice and are within the range of natural variability in wave height (e.g. from wave to wave within a seastate, from hour to hour during the passage of a storm, and in the context of seasonal and interannual variation of wave climate).

6.1.6 Hydrodynamic modelling allows an analysis of the effect of the Proposed Development (alone and cumulatively with neighbouring OWFs) on the tidal regime and tidally driven sediment transport regime. Model results show changes to current speed at the resolution of the model will be less than 0.05 m/s (~10%), which is very small in both absolute and relative terms. The greatest change, a reduction in current speeds, occur directly downstream of the foundation structure and are highly localised. This wake signature dissipates and recovers with distance downstream, becoming less than a 5% reduction within 700 m of the foundation structures (within the range of natural variability and only measurable within a very limited spatial footprint of the wake). The wake is a generally linear feature, aligned to the tidal current direction at the time – which may rotate throughout the tidal cycle. Consistent with the limited scale of change in instantaneous current speed and direction, no meaningful measurable change in residual current speed or direction, nor residual sediment transport is predicted either within the Array Area, or elsewhere.

6.1.7 Empirical relationships were used to calculate an equilibrium scour depth and pattern of scour for the range of potential foundation types. Scour development within the Array Area is expected to be dominated by the action of tidal currents. For the Array Area as a whole, the greatest total Wind Turbine foundation local (deeper, limited extent around individual foundation members) scour footprint is 232,894 m^2, for 67 Wind Turbine 13 m diameter monopile foundations and three OSP 4-legged jacket foundations, this is equivalent to 0.125% of the total Array Area. For the Array Area as a whole, the greatest total Wind Turbine foundation global (shallower, larger extent around the foundation as a whole) scour footprint is 307,012 m^2, for 67 Wind Turbine 3-legged piled jacket foundations and three OSP 4-legged jacket foundations, this is equivalent to 0.164% of the total Array Area. In practice, the thickness of unconsolidated surficial Holocene sediment (i.e. the thickness of erodible material and so the depth limit for local or global scour) is spatially variable across the Array Area and can be locally very thin or absent, which would largely naturally prevent the formation of scour.

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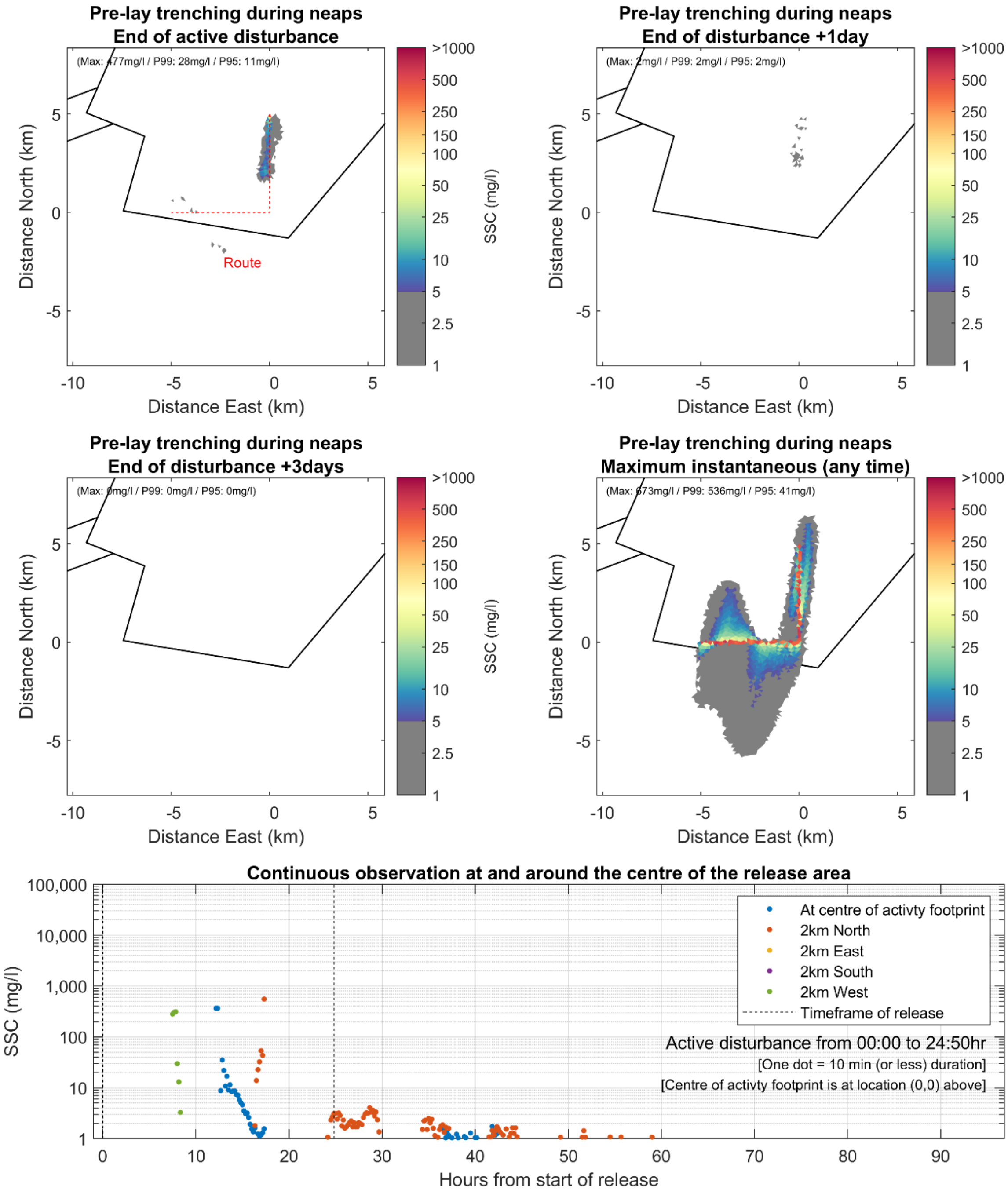
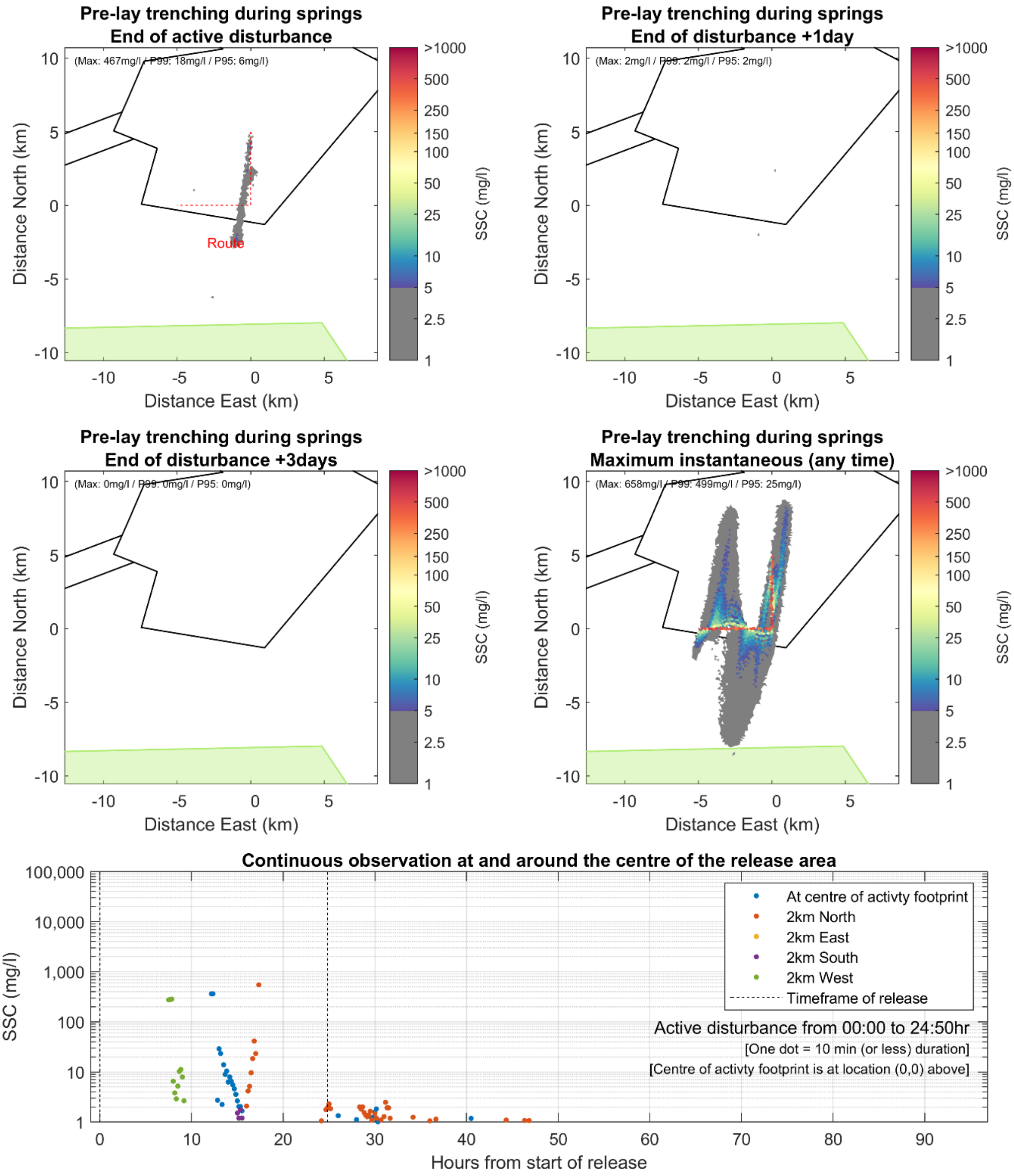
ANNEX A. SUSPENDED SEDIMENT CONCENTRATION FIGURES



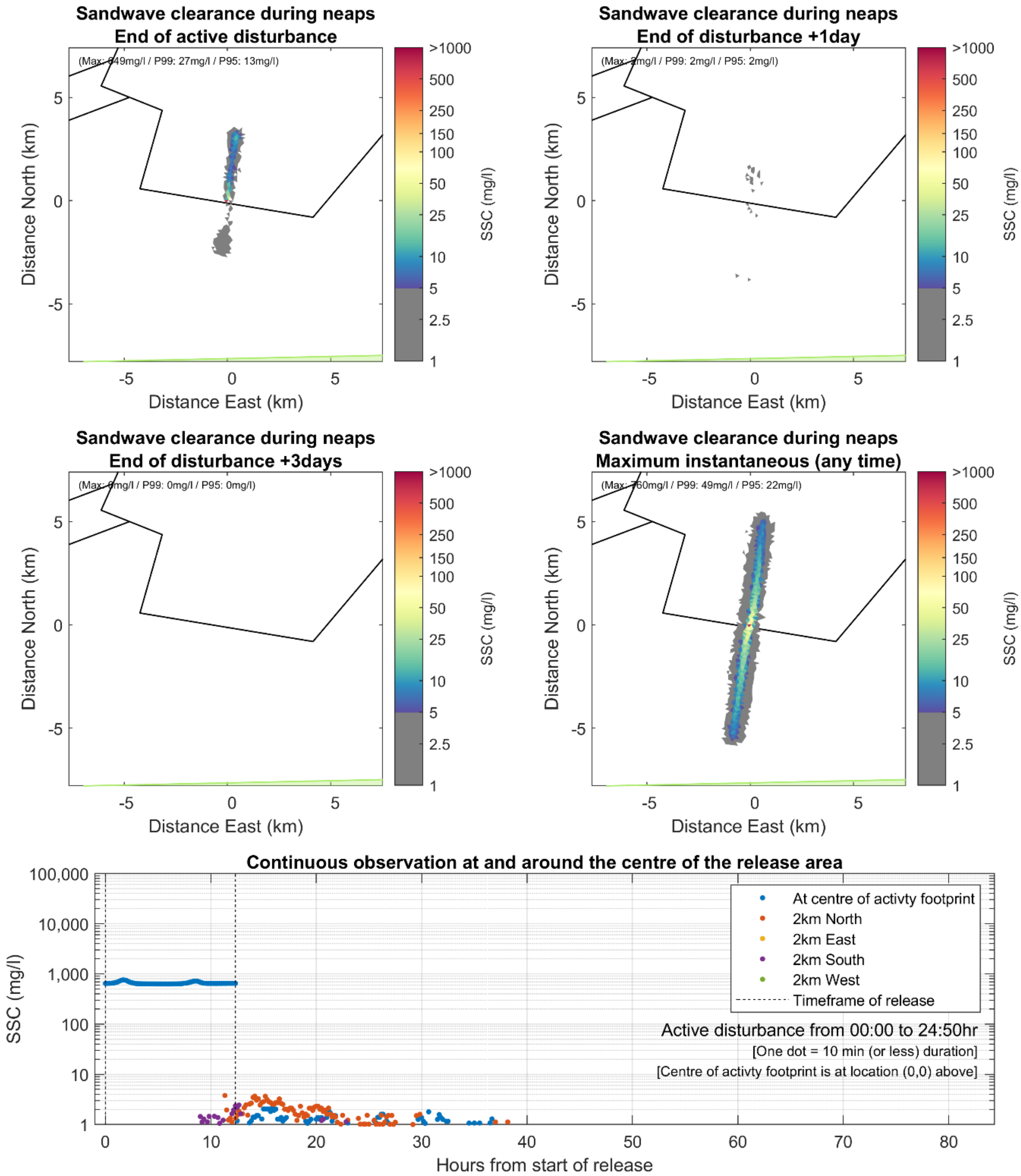
The mobile release simulating the trencher path is represented by the dotted red line. The Array Area and Export Cable Corridor is outlined in black.

Figure A1.1: Increase in Suspended Sediment Concentration as a Result of Scenario 1: Pre-Lay Trenching Using a MFE in the Array Area. Mean Neap Tide



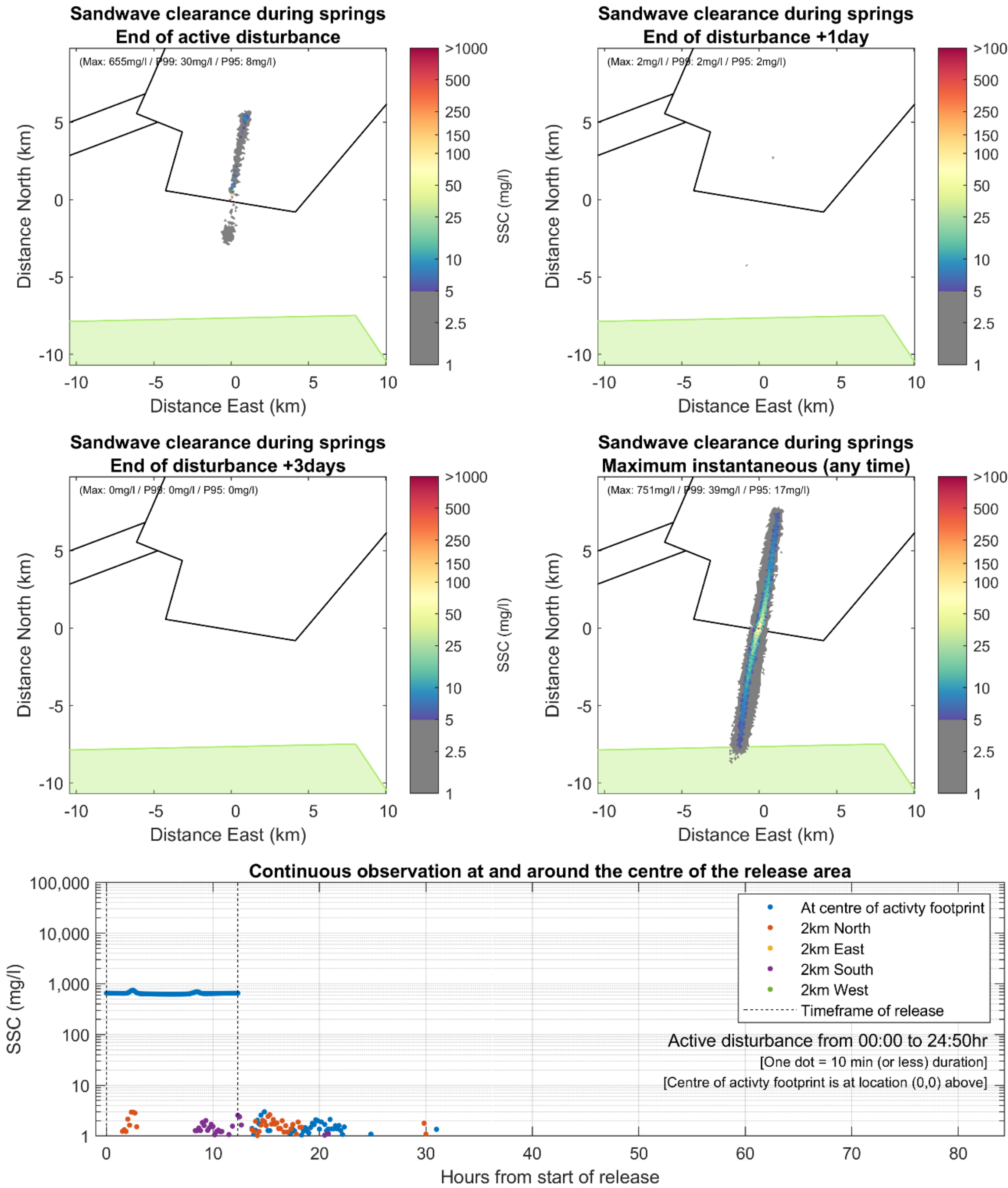
The mobile release simulating the trencher path is represented by the dotted red line. The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.2: Increase in Suspended Sediment Concentration as a Result of Scenario 2: Pre-Lay Trenching Using a MFE in the Array Area. Mean Spring Tide



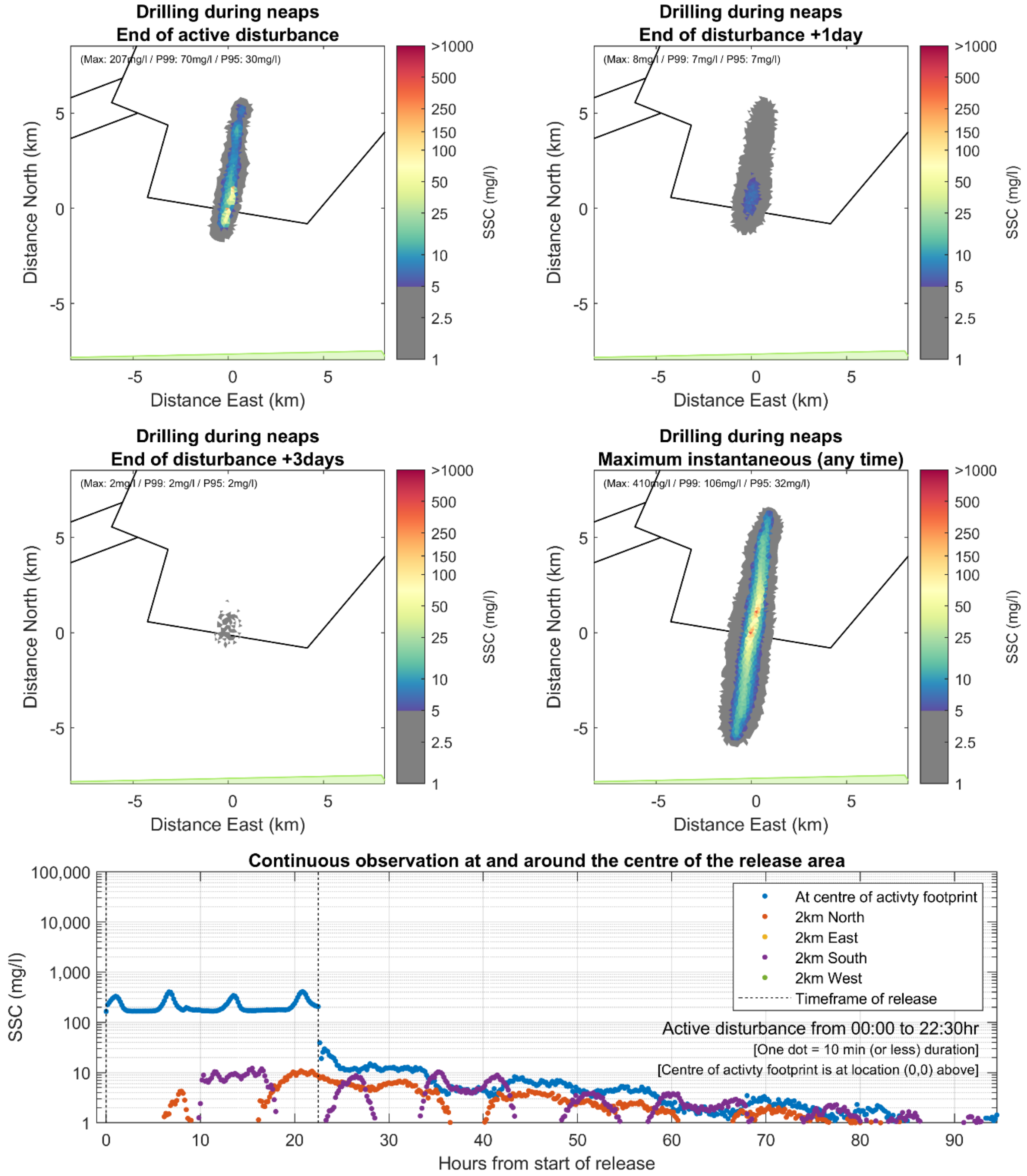
The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.3: Increase in Suspended Sediment Concentration as a Result of Scenario 3: Sandwave Clearance Using a MFE in the Array Area. Mean Neap Tide



The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.4: Increase in Suspended Sediment Concentration as a Result of Scenario 4: Sandwave Clearance Using a MFE in the Array Area. Mean Spring Tide



Drilling during neaps
End of active disturbance

Drilling during neaps
End of disturbance +1day

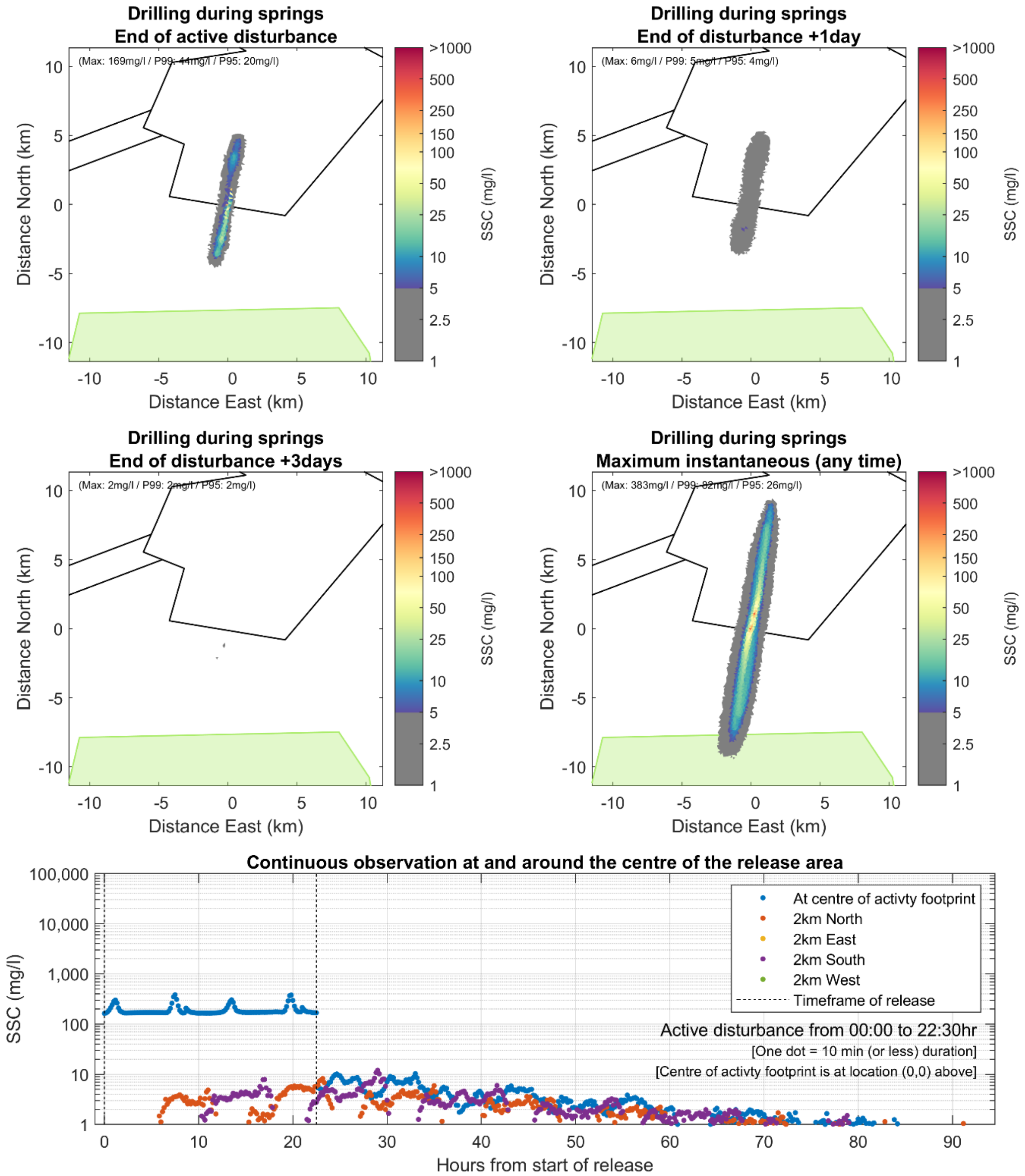
Drilling during neaps
End of disturbance +3days

Drilling during neaps
Maximum instantaneous (any time)

Continuous observation at and around the centre of the release area

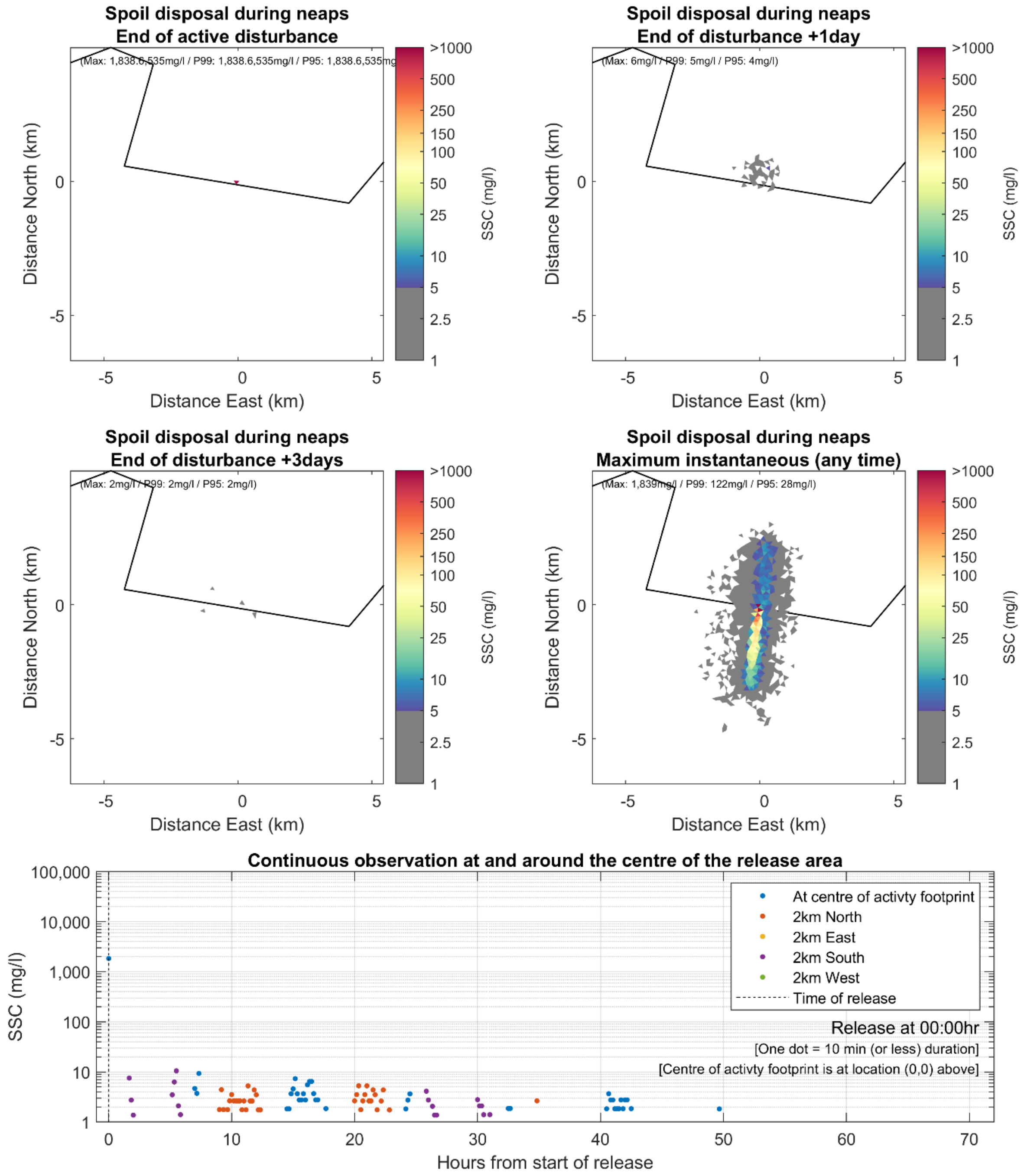
The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.5: Increase in Suspended Sediment Concentration as a Result of Scenario 5: Drilling Two Neighbouring Piles in the Array Area. Mean Neap Tide



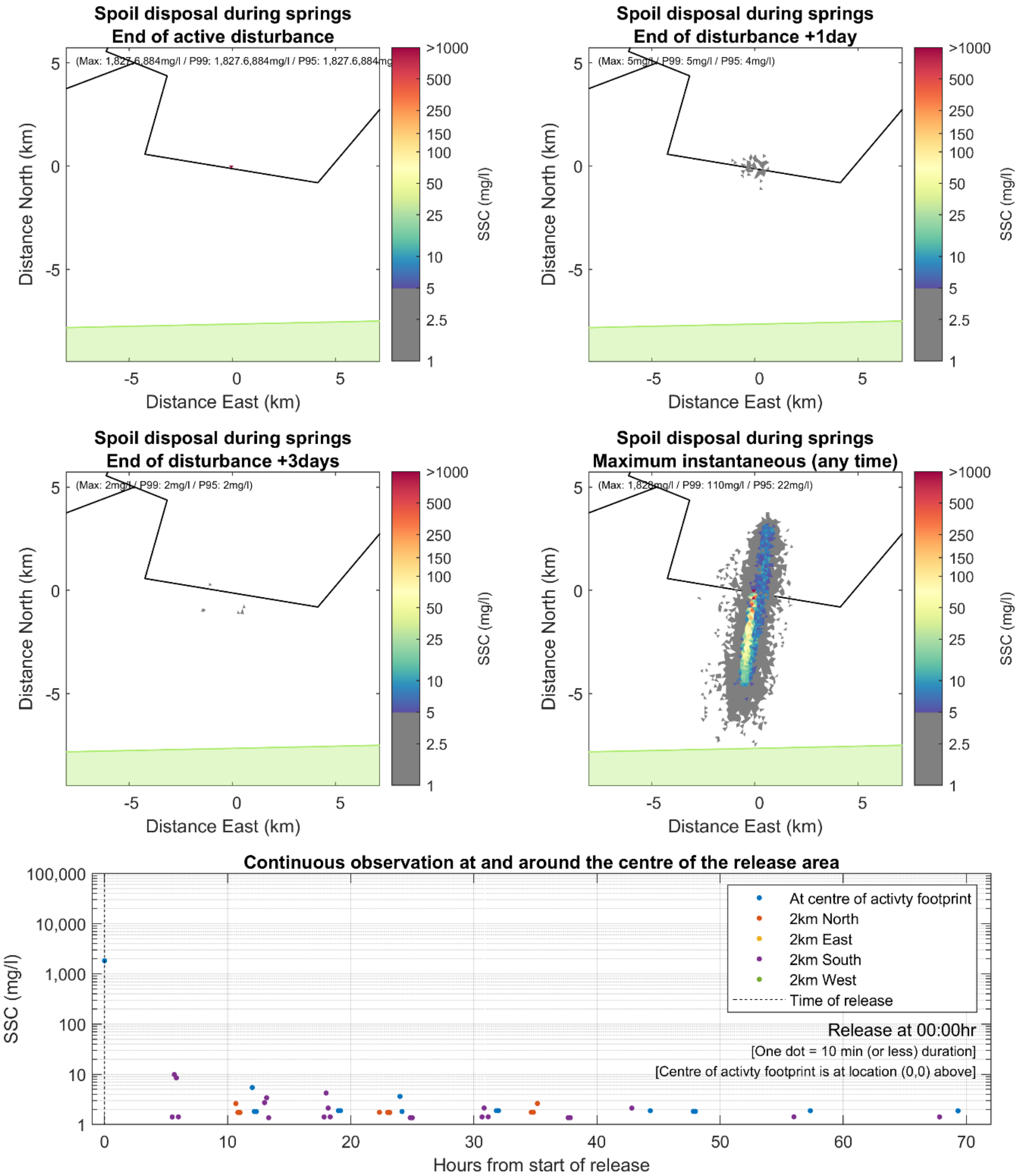
The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.6: Increase in Suspended Sediment Concentration as a Result of Scenario 6: Drilling Two Neighbouring Piles in the Array Area. Mean Spring Tide



The Array Area and Export Cable Corridor is outlined in black.

Figure A1.7: Increase in Suspended Sediment Concentration as a Result of Scenario 7: Dredge Spoil Disposal in the Array Area. Mean Neap Tide



Spoil disposal during springs
End of active disturbance

Spoil disposal during springs
End of disturbance +1day

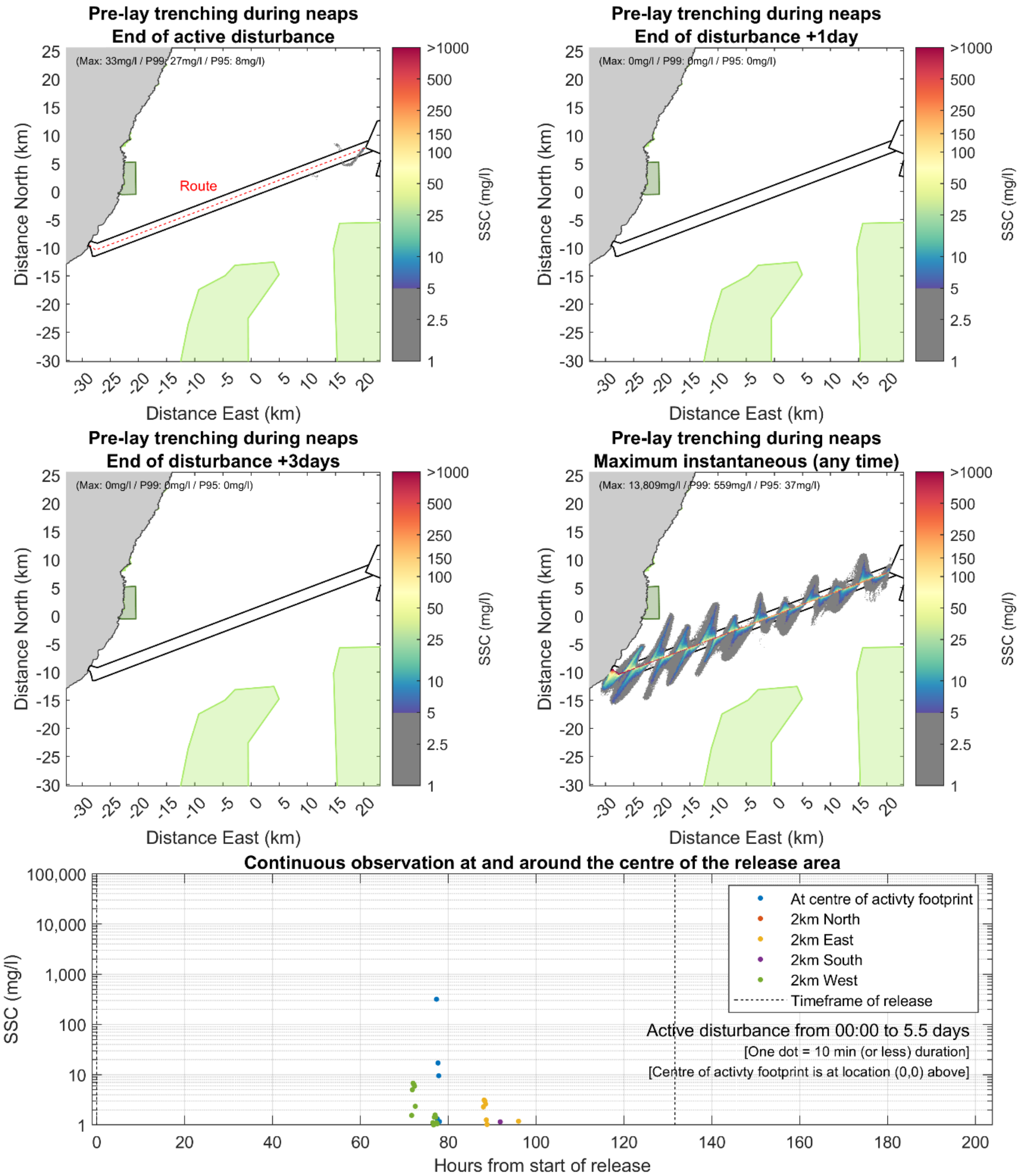
Spoil disposal during springs
End of disturbance +3days

Spoil disposal during springs
Maximum instantaneous (any time)

Continuous observation at and around the centre of the release area

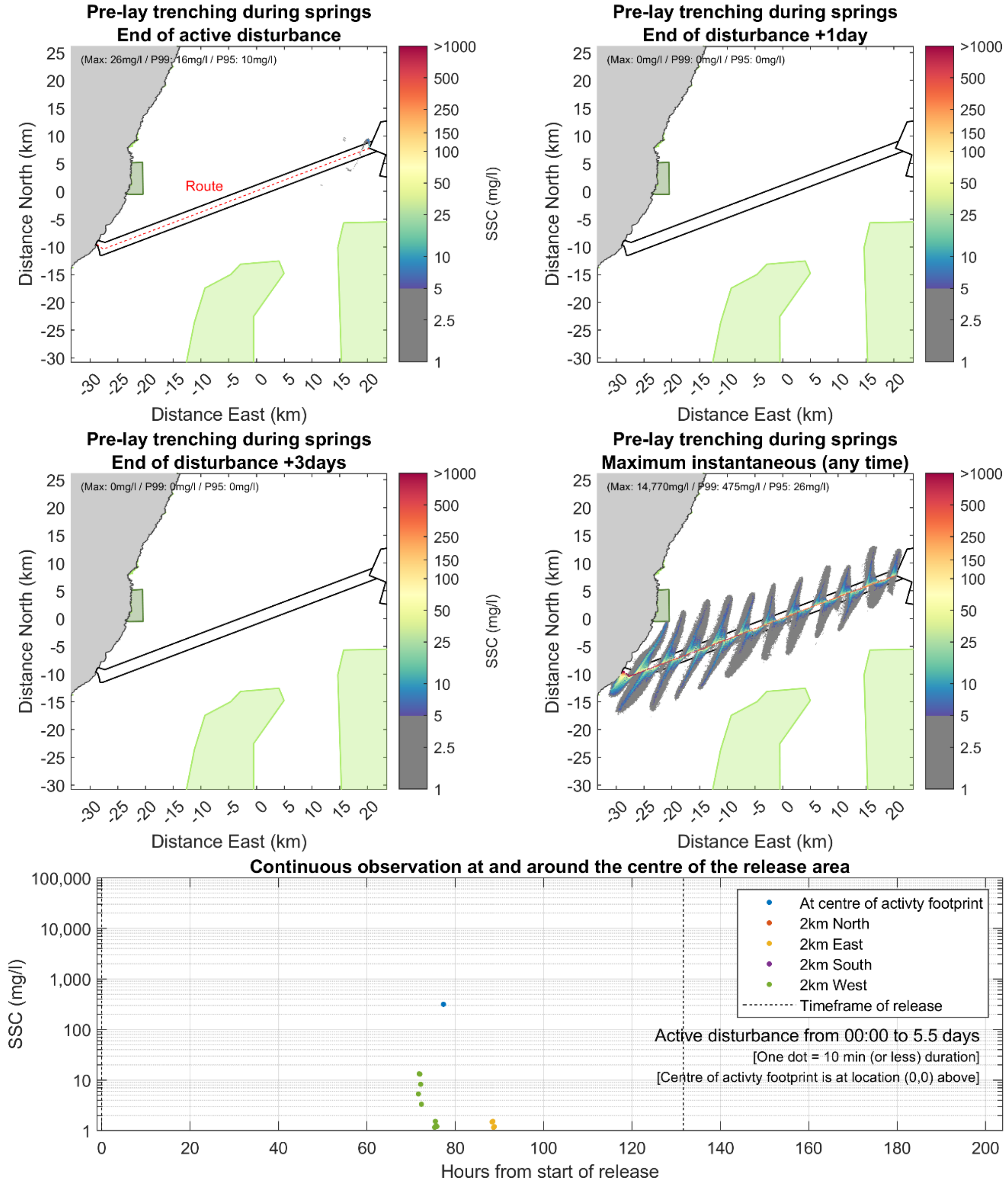
The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green.

Figure A1.8: Increase in Suspended Sediment Concentration as a Result of Scenario 8: Dredge Spoil Disposal in the Array Area. Mean Spring Tide



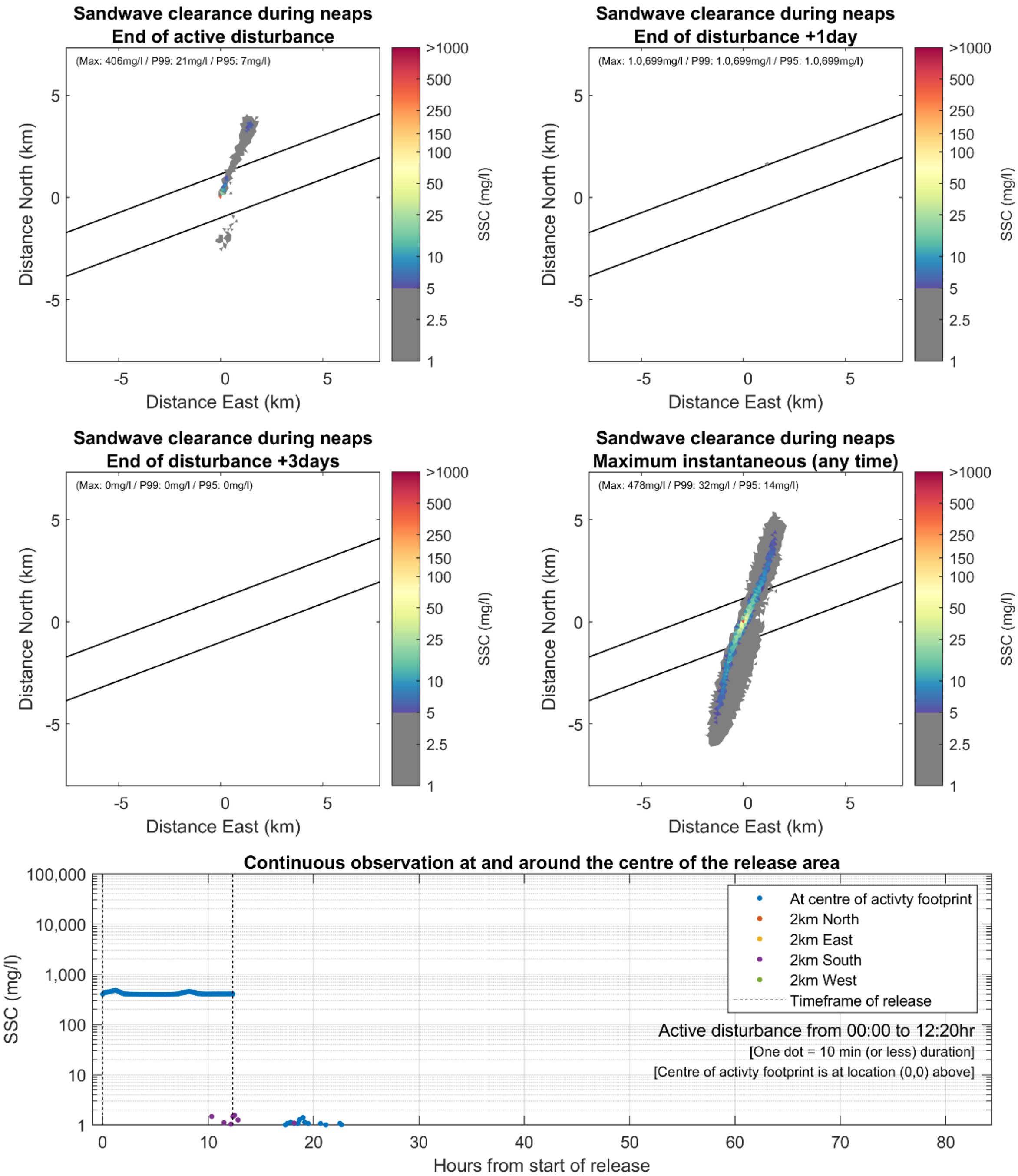
The mobile release simulating the trencher path is represented by the dotted red line. The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green, SPAs are shown in dark green.

Figure A1.9: Increase in Suspended Sediment Concentration as a Result of Scenario 9: Pre-Lay Trenching Using a MFE Along the Length of the Export Cable Corridor. Mean Neap Tide



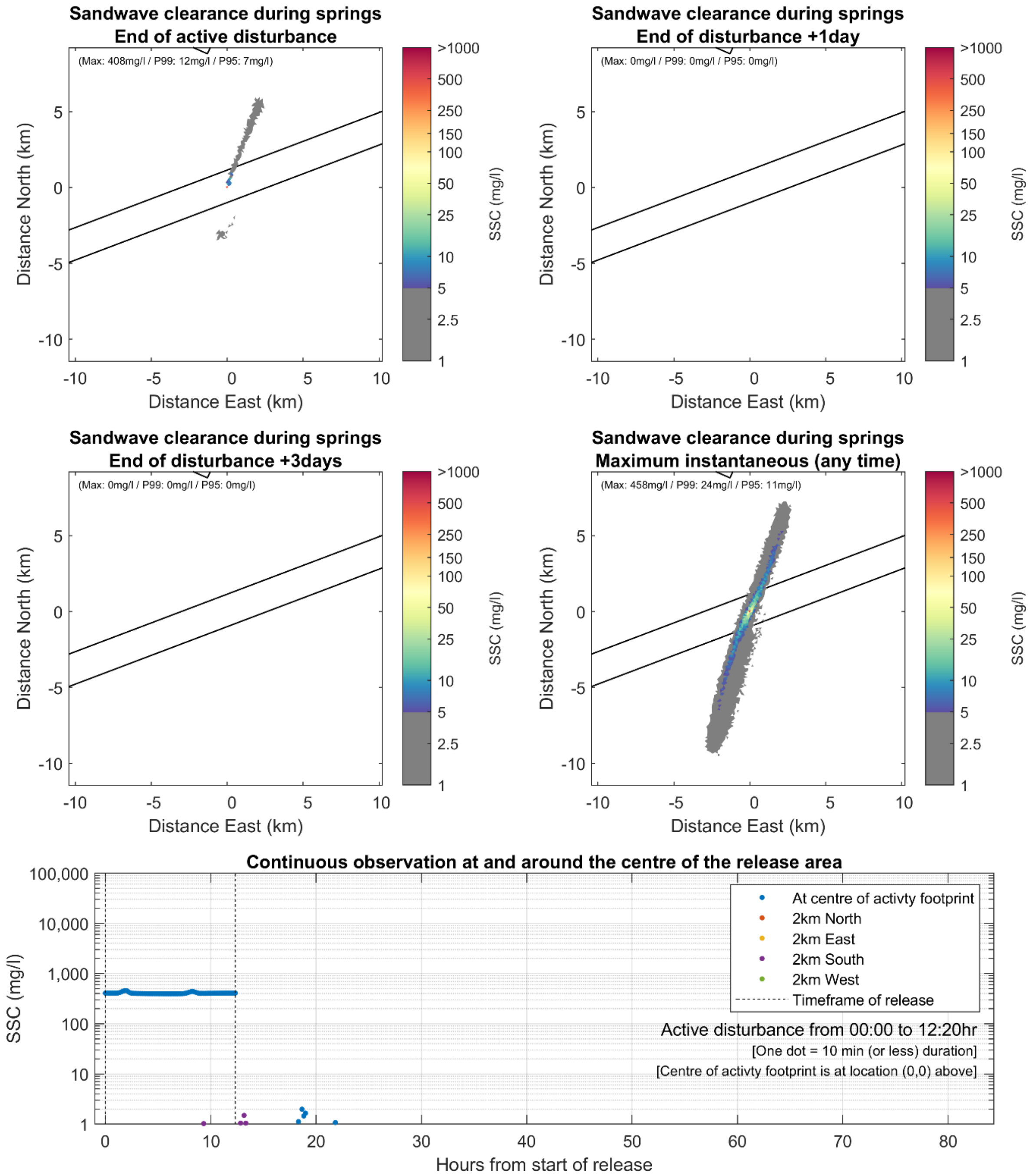
The mobile release simulating the trencher path is represented by the dotted red line. The Array Area and Export Cable Corridor is outlined in black. MPAs are shown in light green, SPAs are shown in dark green.

Figure A1.10: Increase in Suspended Sediment Concentration as a Result of Scenario 10: Pre-Lay Trenching Using a MFE Along the Length of the Export Cable Corridor. Mean Spring Tide



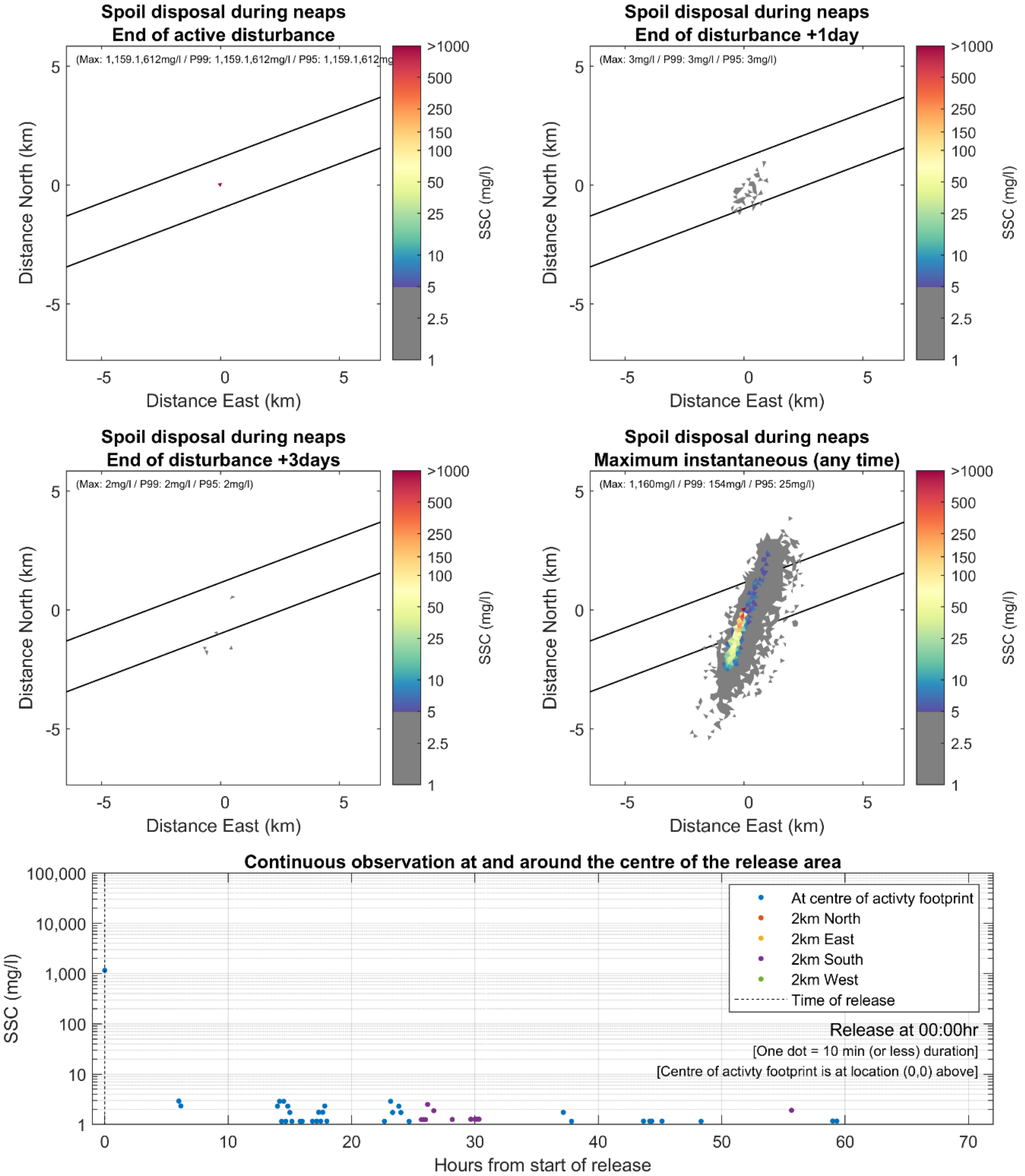
The Export Cable Corridor is outlined in black.

Figure A1.11: Increase in Suspended Sediment Concentration as a Result of Scenario 11: Sandwave Clearance Using a MFE at a Central Location in the Export Cable Corridor. Mean Neap Tide



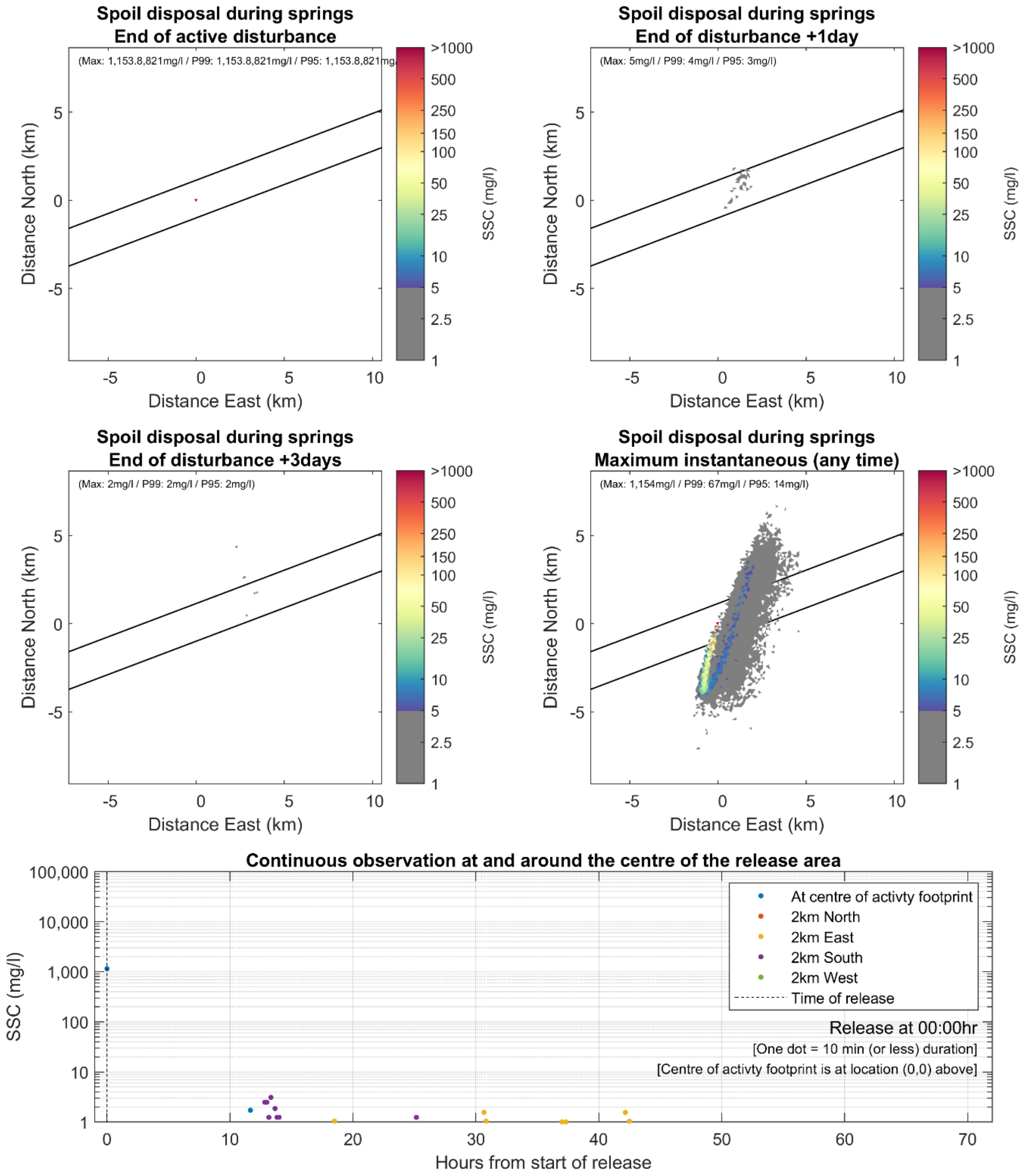
The Export Cable Corridor is outlined in black.

Figure A1.12: Increase in Suspended Sediment Concentration as a Result of Scenario 12: Sandwave Clearance Using a MFE at a Central Location in the Export Cable Corridor. Mean Spring Tide



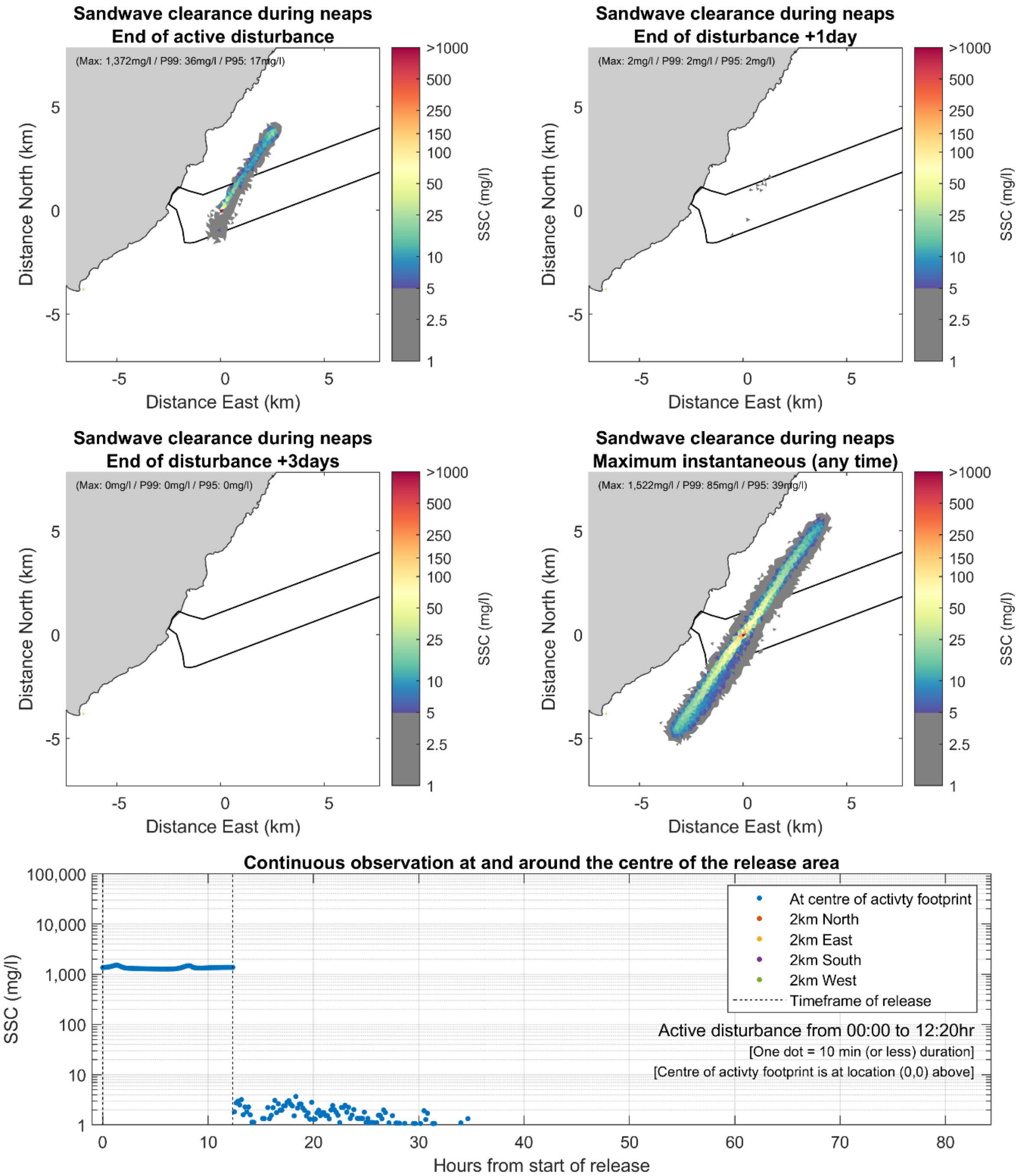
The Export Cable Corridor is outlined in black.

Figure A1.13: Increase in Suspended Sediment Concentration as a Result of Scenario 13: Dredge Spoil Disposal at a Central Location in the Export Cable Corridor. Mean Neap Tide



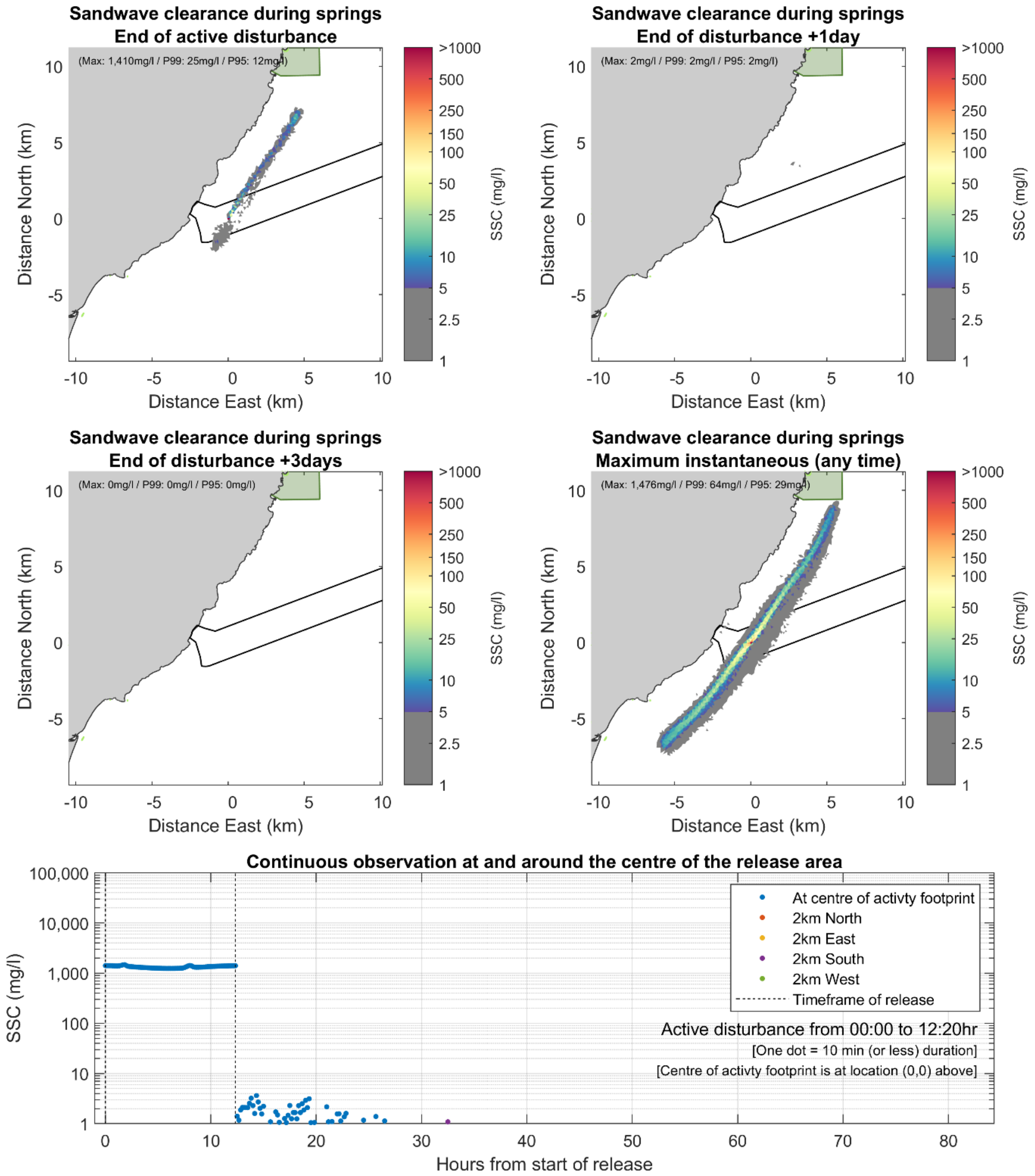
The Export Cable Corridor is outlined in black.

Figure A1.14: Increase in Suspended Sediment Concentration as a Result of Scenario 14: Dredge Spoil Disposal at a Central Location in the Export Cable Corridor. Mean Spring Tide



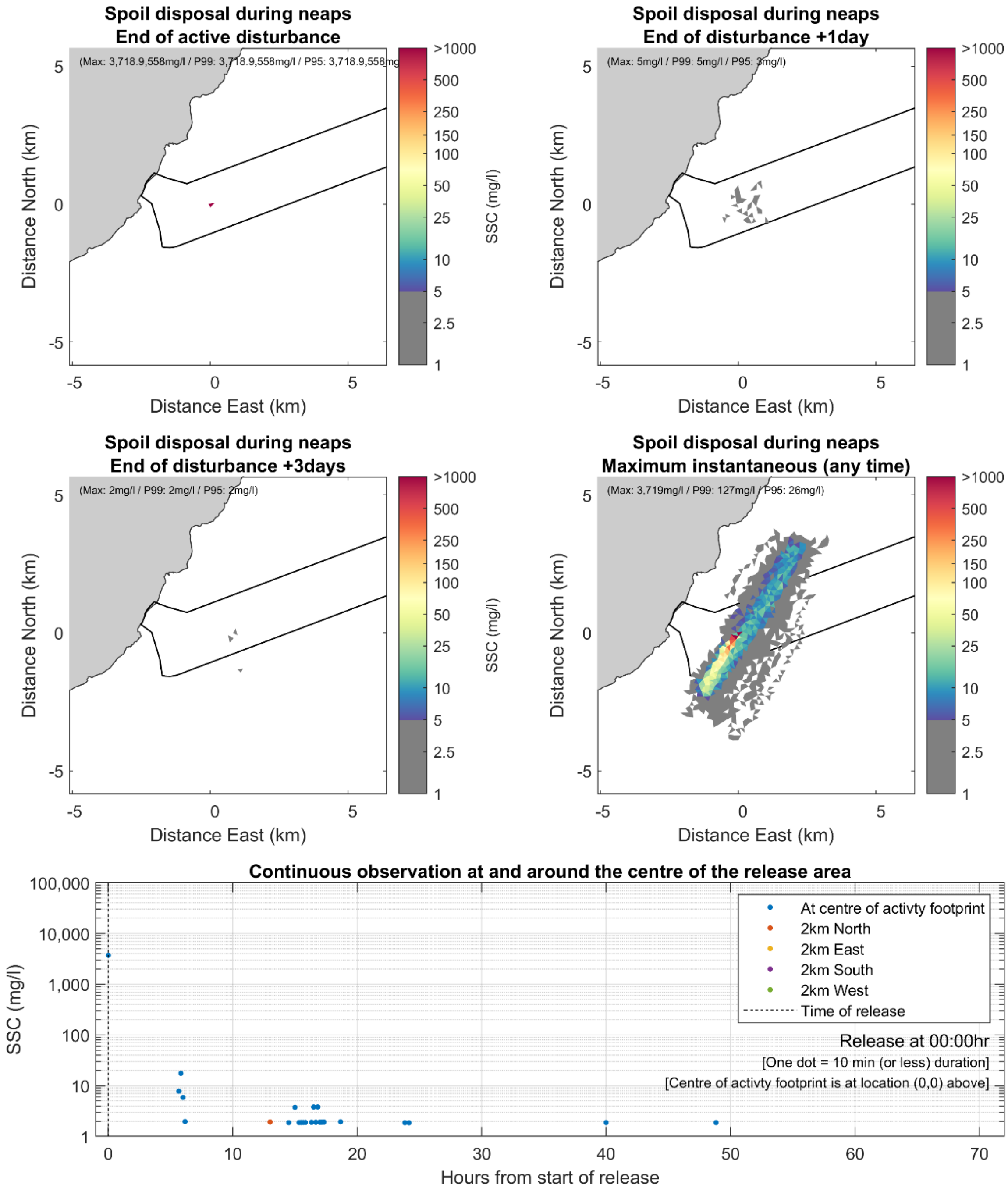
The Export Cable Corridor is outlined in black.

Figure A1.15: Increase in Suspended Sediment Concentration as a Result of Scenario 15: Sandwave Clearance Using a MFE at a Nearshore Location in the Export Cable Corridor. Mean Neap Tide



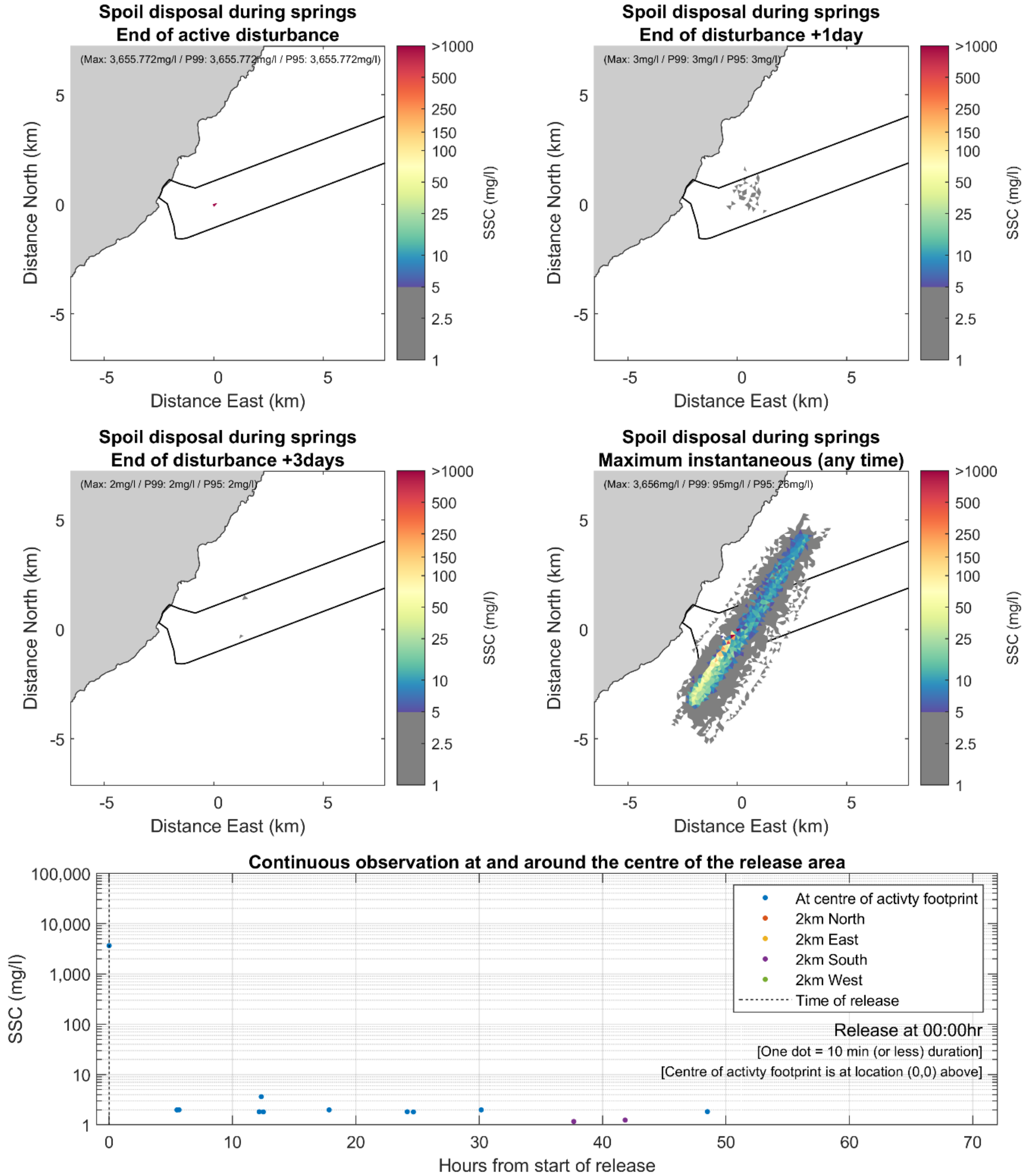
The Export Cable Corridor is outlined in black. SPAs shown in dark green.

Figure A1.16: Increase in Suspended Sediment Concentration as a Result of Scenario 16: Sandwave Clearance Using a MFE at a Nearshore Location in the Export Cable Corridor. Mean Spring Tide



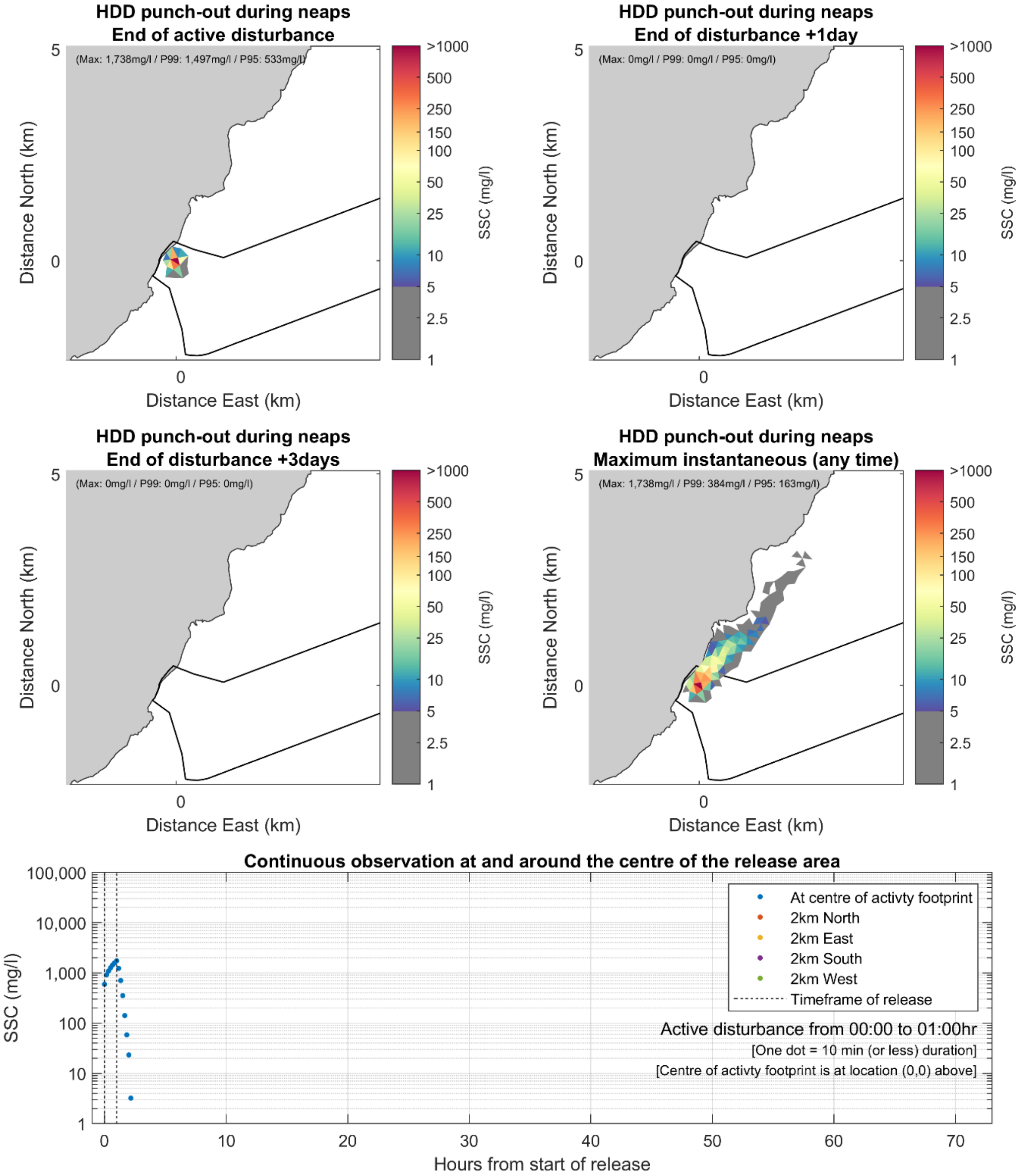
The Export Cable Corridor is outlined in black.

Figure A1.17: Increase in Suspended Sediment Concentration as a Result of Scenario 17: Dredge Spoil Disposal at a Nearshore Location in the Export Cable Corridor. Mean Neap Tide



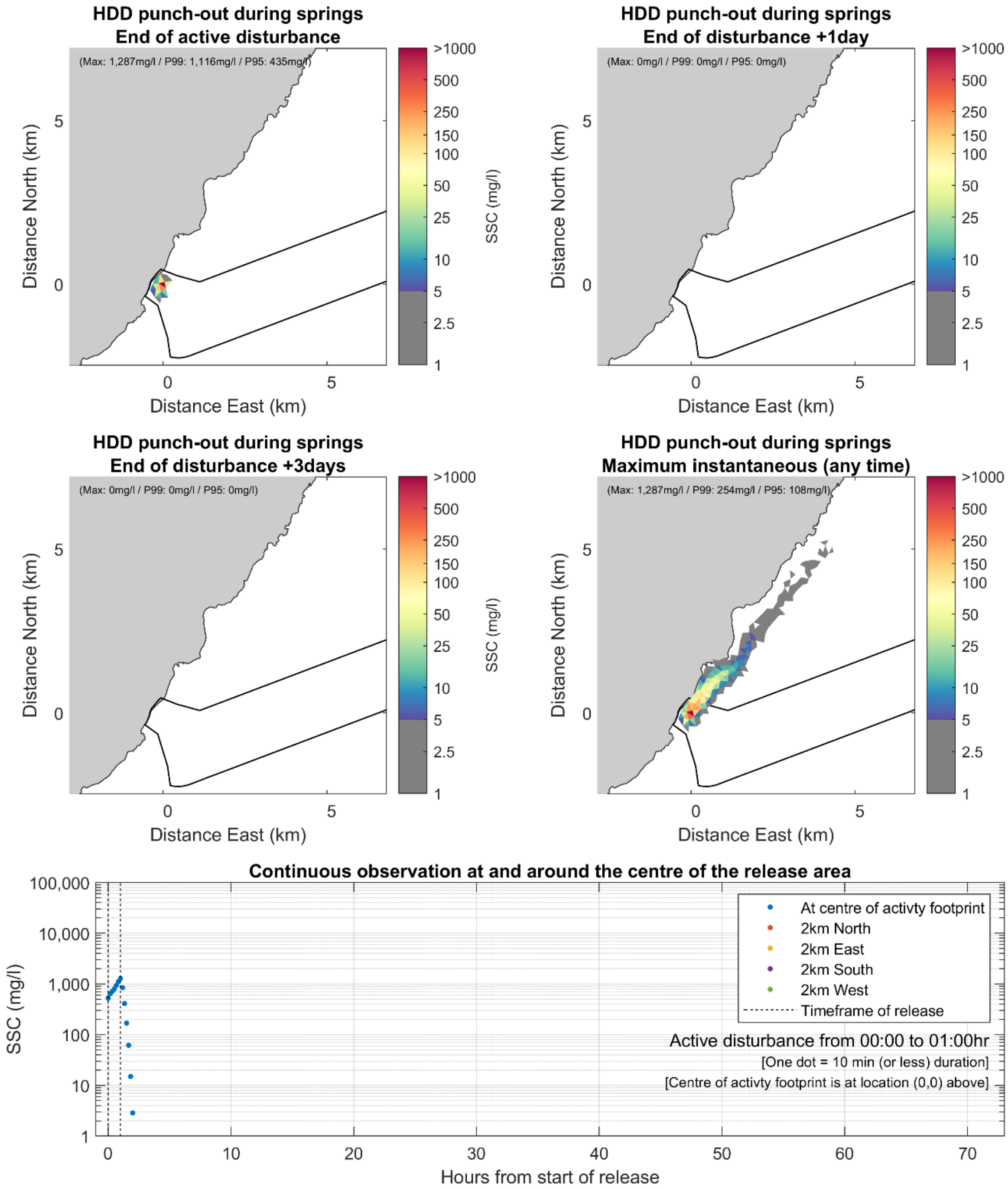
The Export Cable Corridor is outlined in black.

Figure A1.18: Increase in Suspended Sediment Concentration as a Result of Scenario 18: Dredge Spoil Disposal at a Nearshore Location in the Export Cable Corridor. Mean Spring Tide



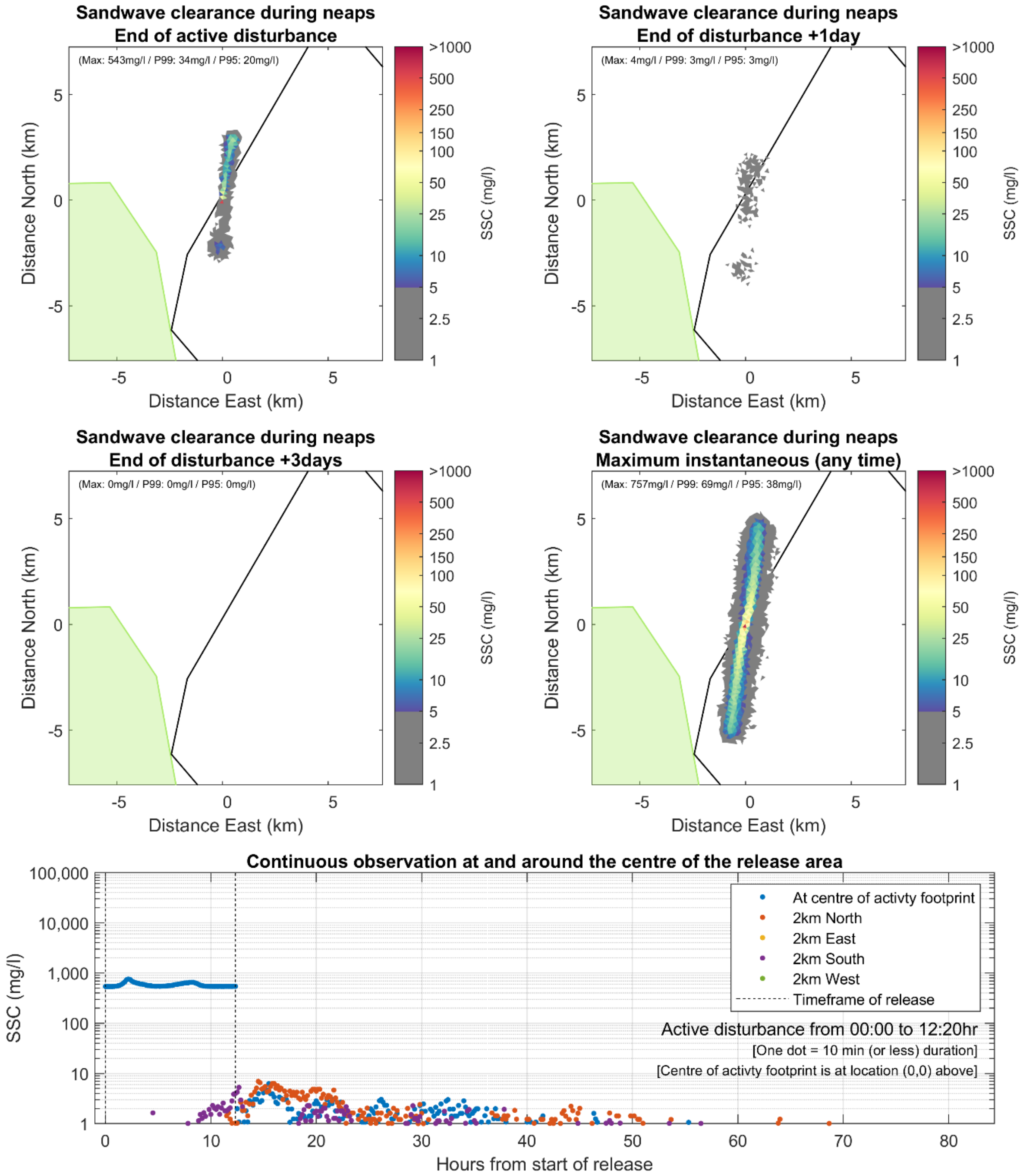
The Export Cable Corridor is outlined in black.

Figure A1.19: Increase in Suspended Sediment Concentration as a Result of Scenario 19: Landfall Punch Out Bentonite Release at a Nearshore Location in the Export Cable Corridor. Mean Neap Tide



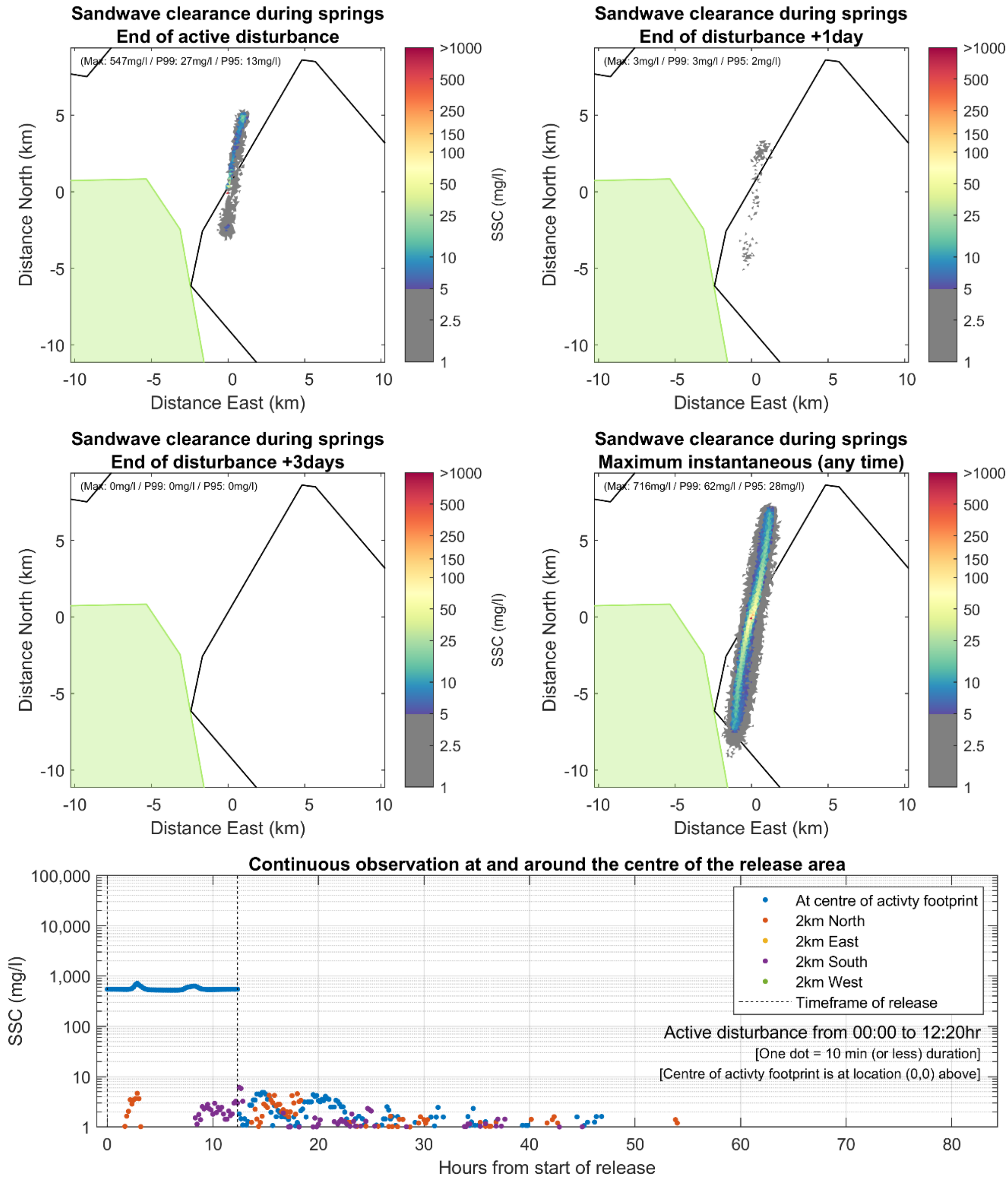
The Export Cable Corridor is outlined in black.

Figure A1.20: Increase in Suspended Sediment Concentration as a Result of Scenario 20: Landfall Punch Out Bentonite Release at a Nearshore Location in the Export Cable Corridor. Mean Spring Tide



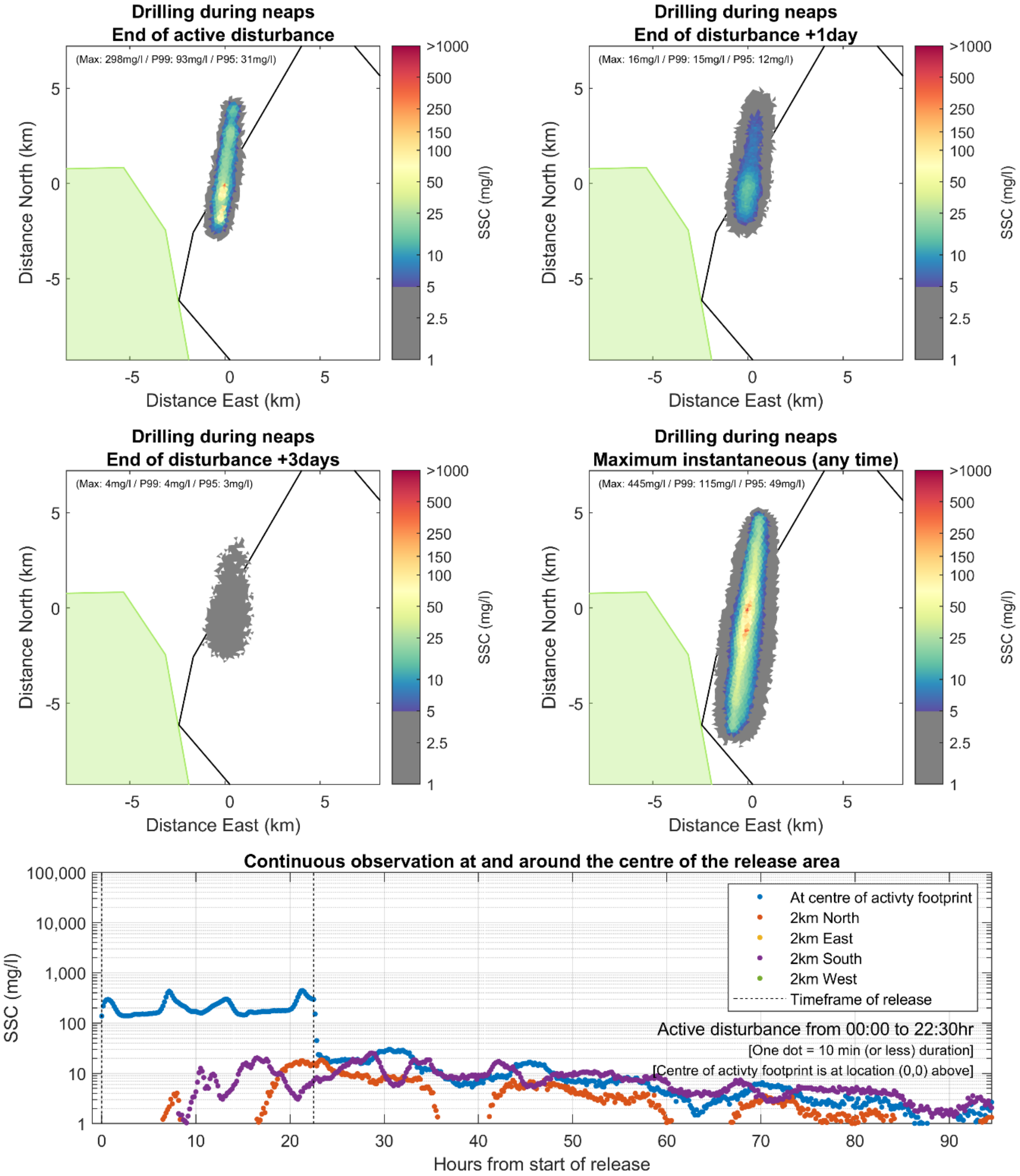
The Morven North array area is outlined in black. MPAs are shown in lights green.

Figure A1.21: Increase in Suspended Sediment Concentration as a Result of Scenario 21: Sandwave Clearance Using a MFE in the Morven North Array Area. Mean Neap Tide



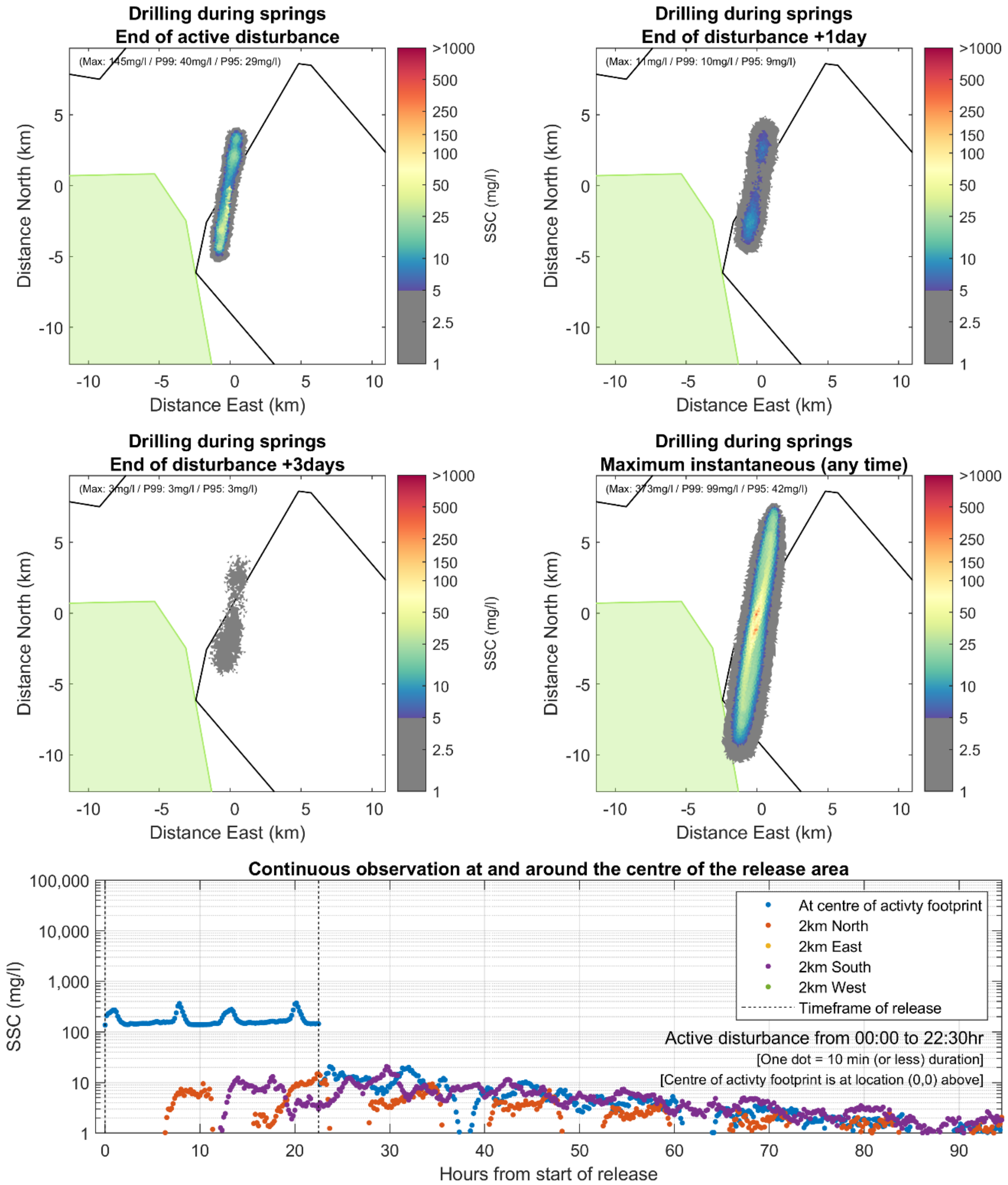
The Morven North array area is outlined in black. MPAs are shown in lights green.

Figure A1.22: Increase in Suspended Sediment Concentration as a Result of Scenario 22: Sandwave Clearance Using a MFE in the Morven North Array Area. Mean Spring Tide



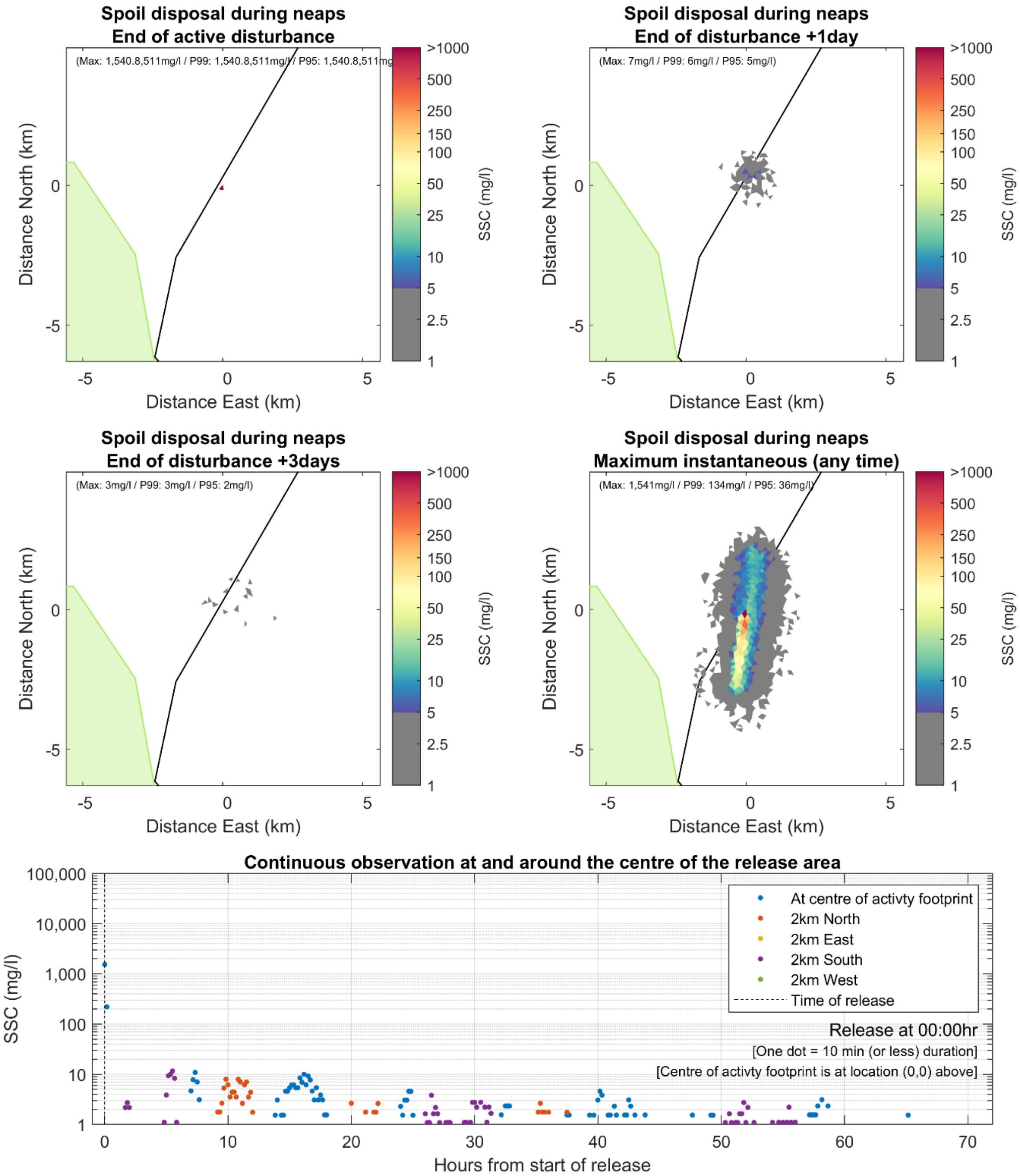
The Morven North array area is outlined in black. MPAs are shown in lights green.

Figure A1.23: Increase in Suspended Sediment Concentration as a Result of Scenario 23: Drilling Two Neighbouring Piles in the Morven North Array Area. Mean Neap Tide



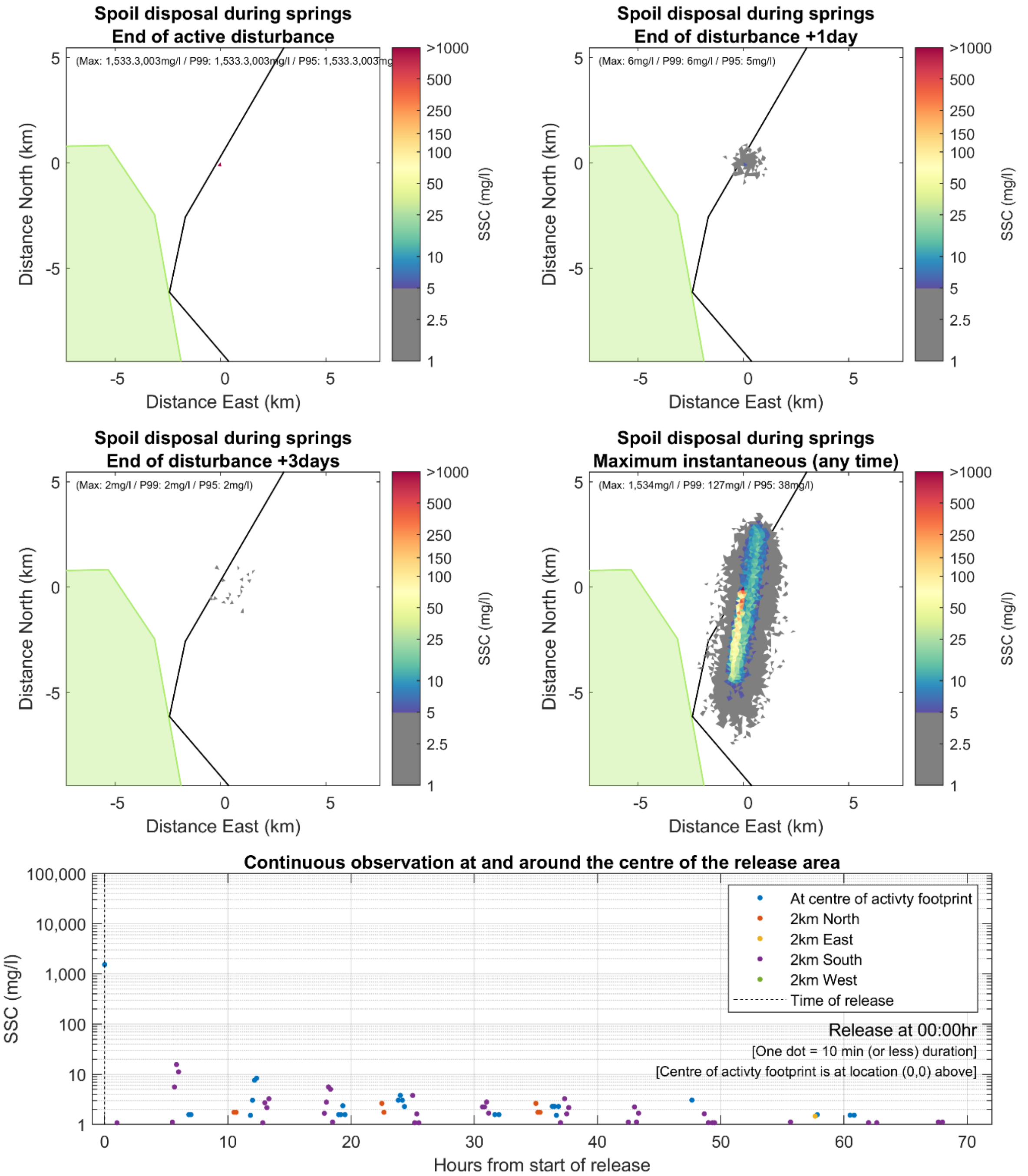
The Morven North array area is outlined in black. MPAs are shown in lights green.

Figure A1.24: Increase in Suspended Sediment Concentration as a Result of Scenario 24: Drilling Two Neighbouring Piles in the Morven North Array Area. Mean Spring Tide



The Morven North array area is outlined in black. MPAs are shown in lights green.

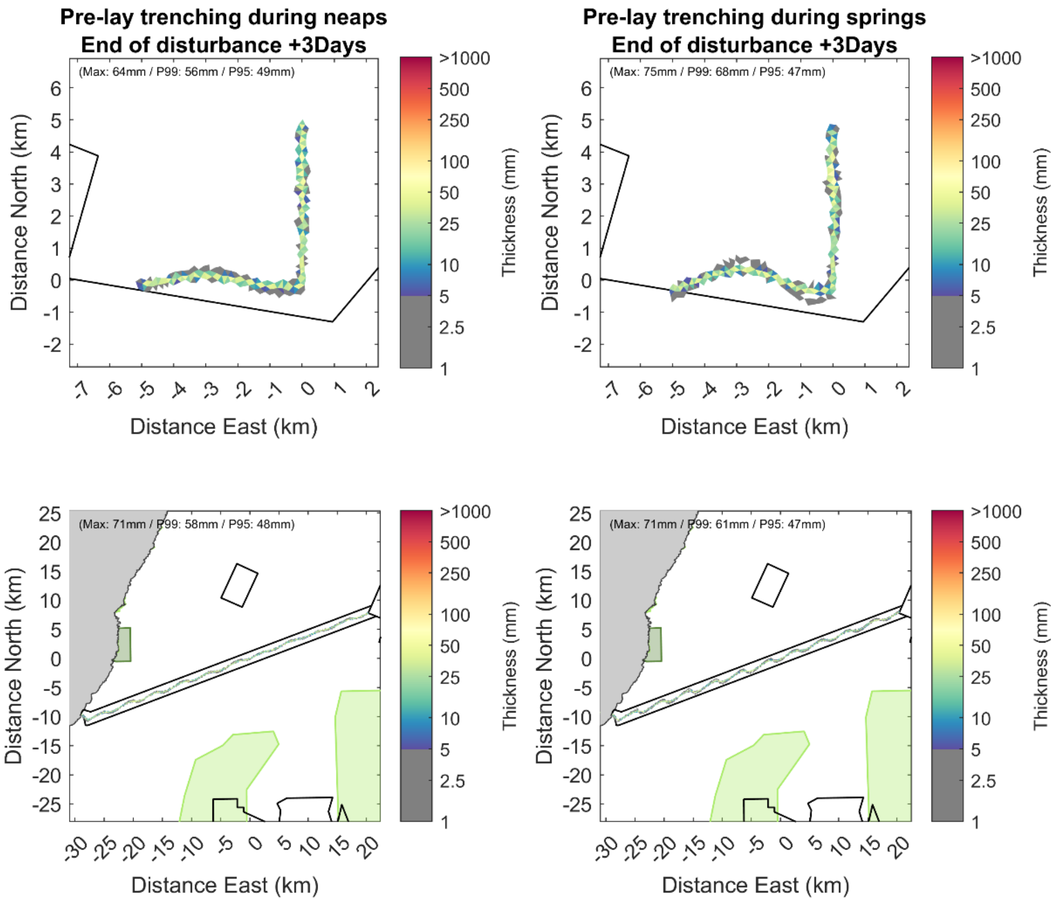
Figure A1.25: Increase in Suspended Sediment Concentration as a Result of Scenario 25: Dredge Spoil Disposal in the Morven North Array Area. Mean Neap Tide



The Morven North array area is outlined in black. MPAs are shown in lights green.

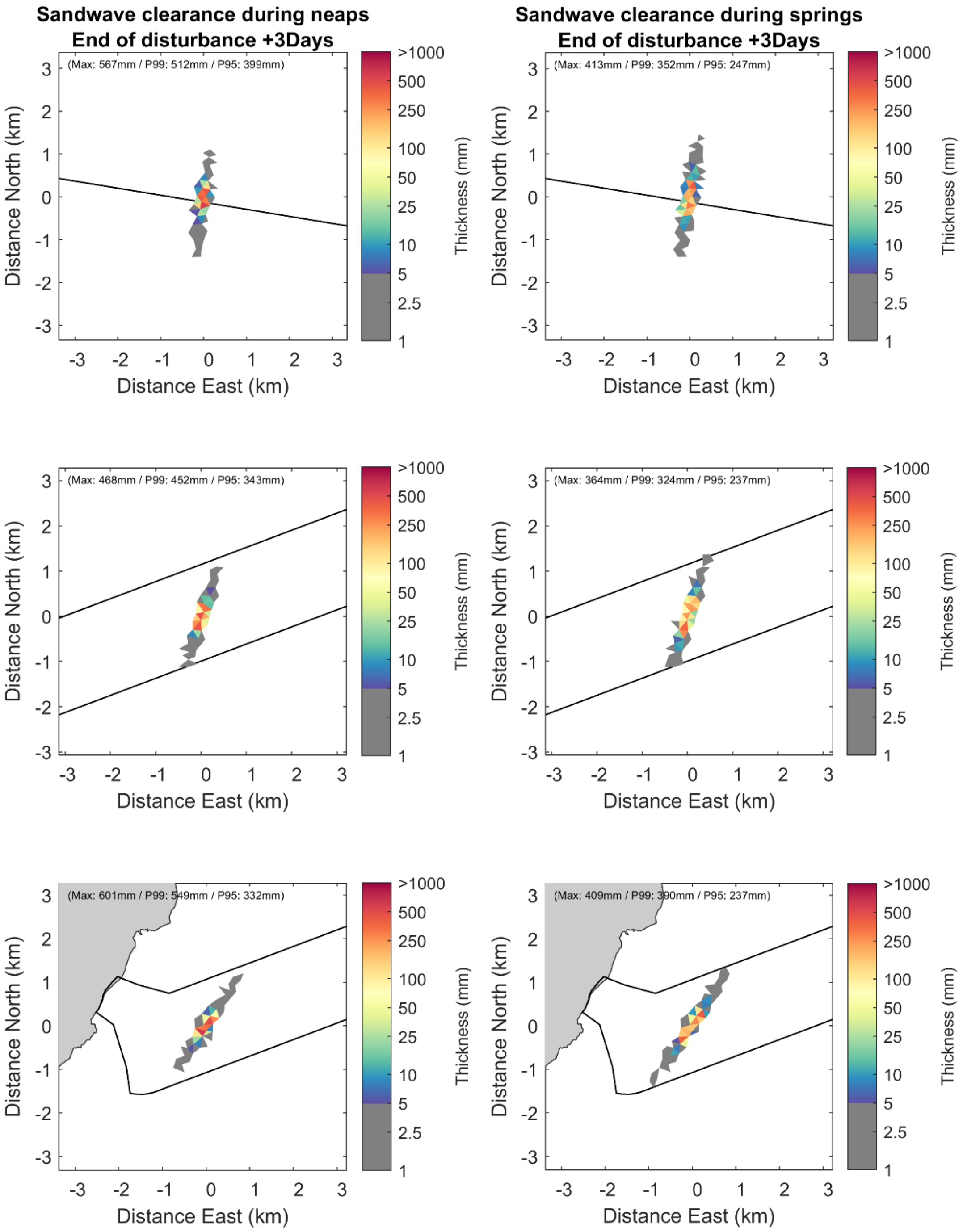
Figure A1.26: Increase in Suspended Sediment Concentration as a Result of Scenario 26: Dredge Spoil Disposal in the Morven North Array Area. Mean Spring Tide

ANNEX B. SEABED DEPOSITION THICKNESS FIGURES



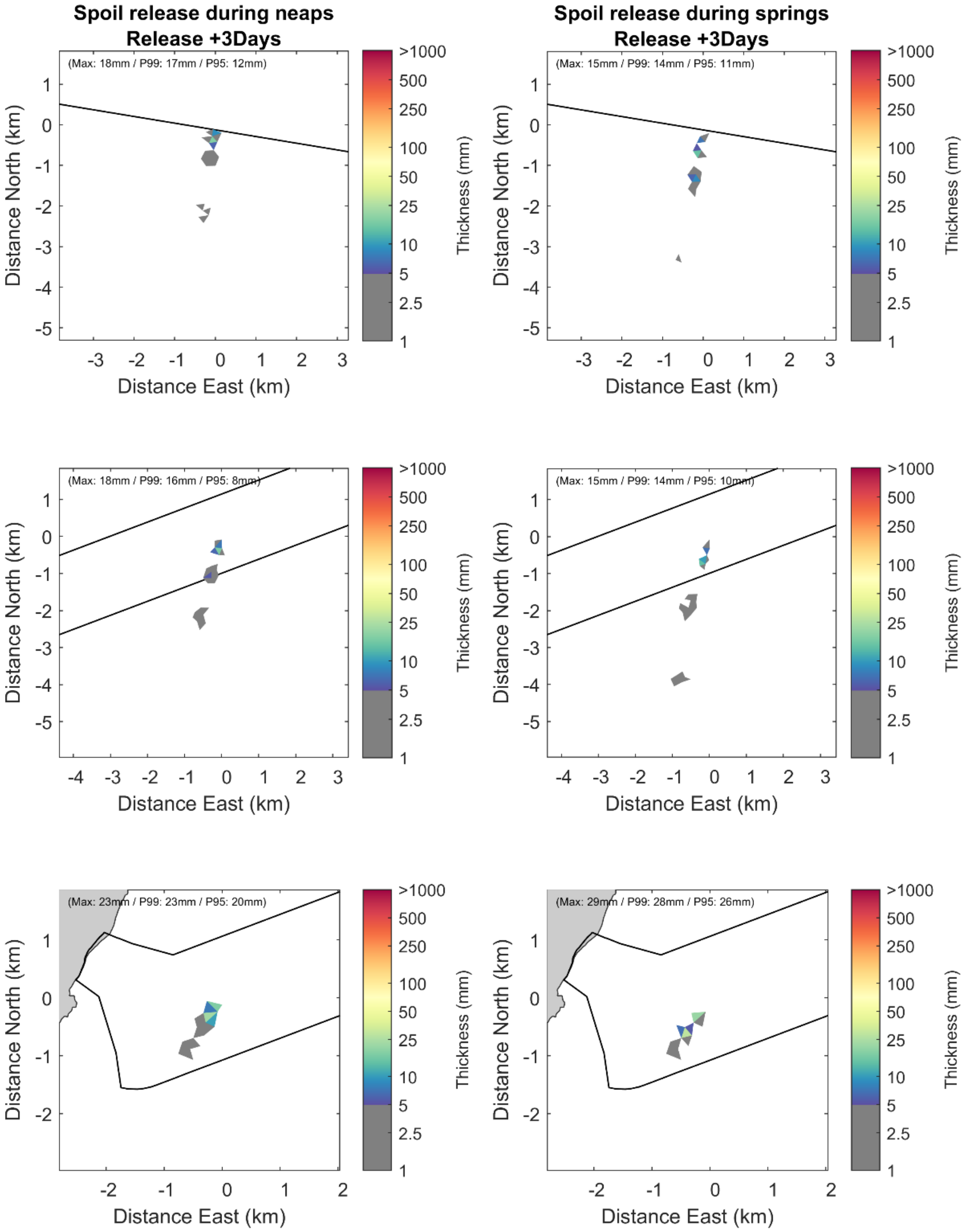
The Array Area and Export Cable Corridor is outlined in black. Regions designated as SPAs are shown in dark green and regions designated as MPAs are shown in light green.

Figure B1.1: Sediment Settlement Thickness as a Result of Pre-Lay Trenching Using a MFE in the Array Area and Along the Export Cable Corridor. Mean Spring (right) and Mean Neap (left) Tides



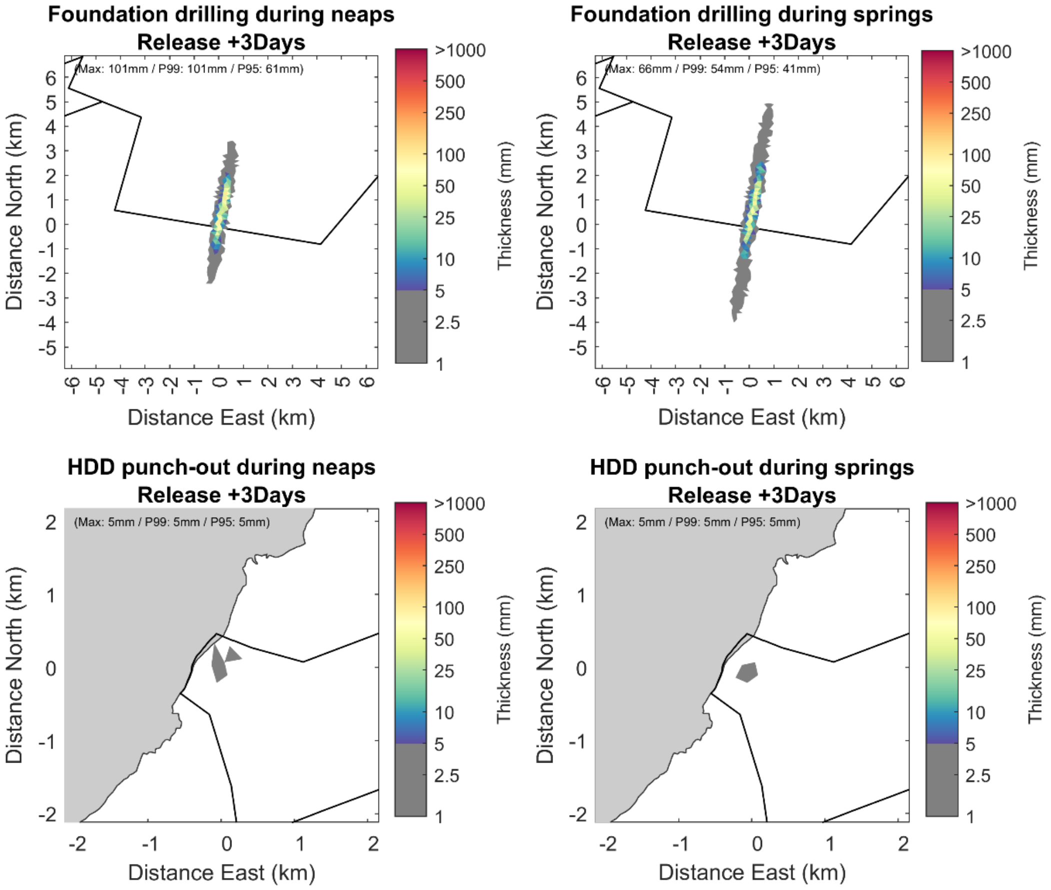
The Array Area and Export Cable Corridor is outlined in black.

Figure B1.2: Sediment Settlement Thickness as a Result Of Sandwave Clearance Using a MFE in the Array Area (top), and at the Centre (middle) and Nearshore (bottom) Regions of the Export Cable Corridor. Mean Spring (right) and Mean Neap (left) Tides



The Array Area and Export Cable Corridor is outlined in black.

Figure B1.3: Sediment Settlement Thickness as a Result of the Passive Phase Plume From Dredge Spoil Disposal in the Array Area (top), and at the Centre (middle) and Nearshore (bottom) Regions of the Export Cable Corridor. Mean Spring (right) and Mean Neap (left) Tides



Foundation drilling during neaps Release +3Days

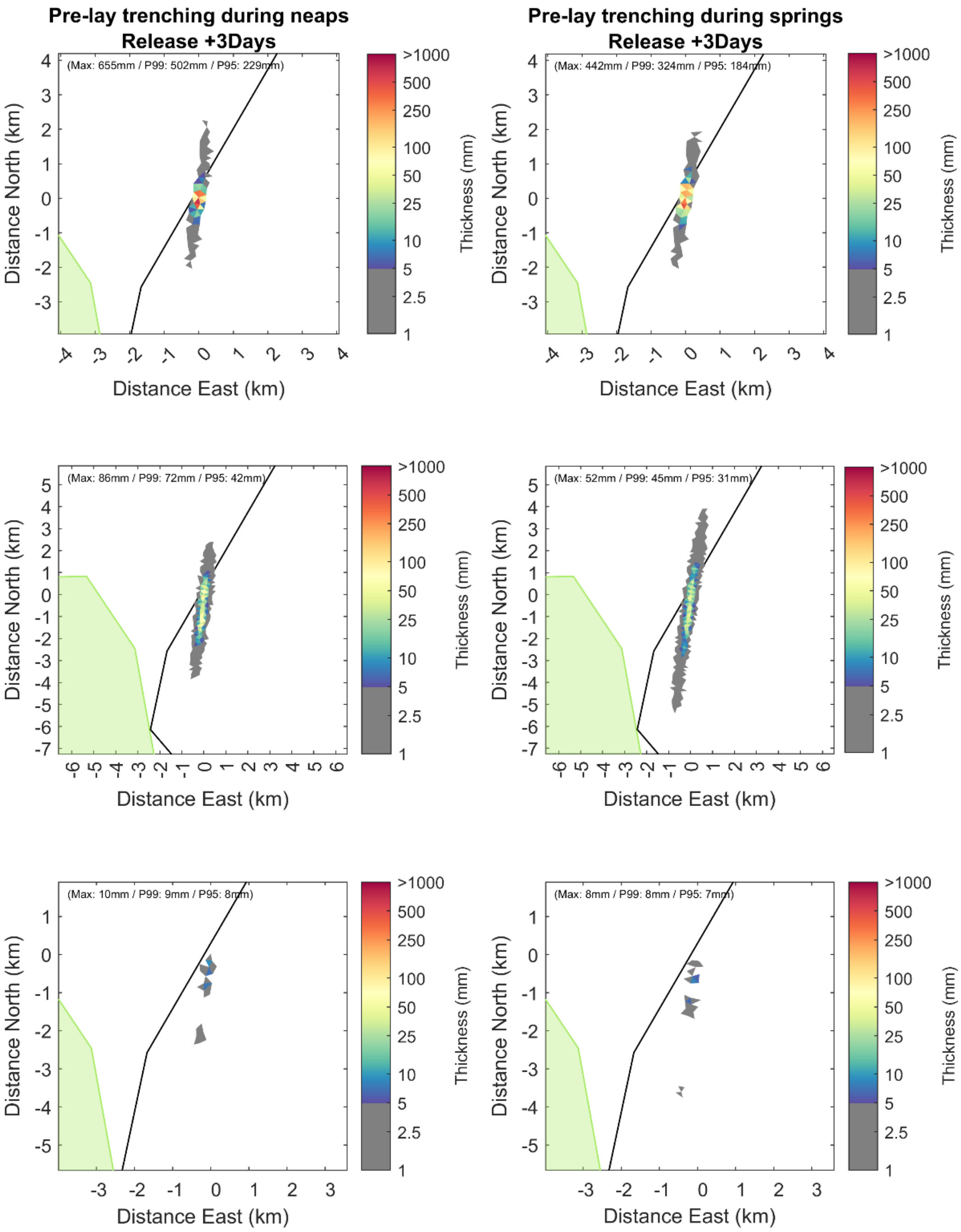
Foundation drilling during springs Release +3Days

HDD punch-out during neaps Release +3Days

HDD punch-out during springs Release +3Days

The Array Area and Export Cable Corridor is outlined in black.

Figure B1.4: Sediment Settlement Thickness as a Result of Drilling Activities (Drilling Piles and Landfall Punch Out) in the Array Area (top) and Nearshore Exit Point (bottom). Mean Spring (right) and Mean Neap (left) Tides



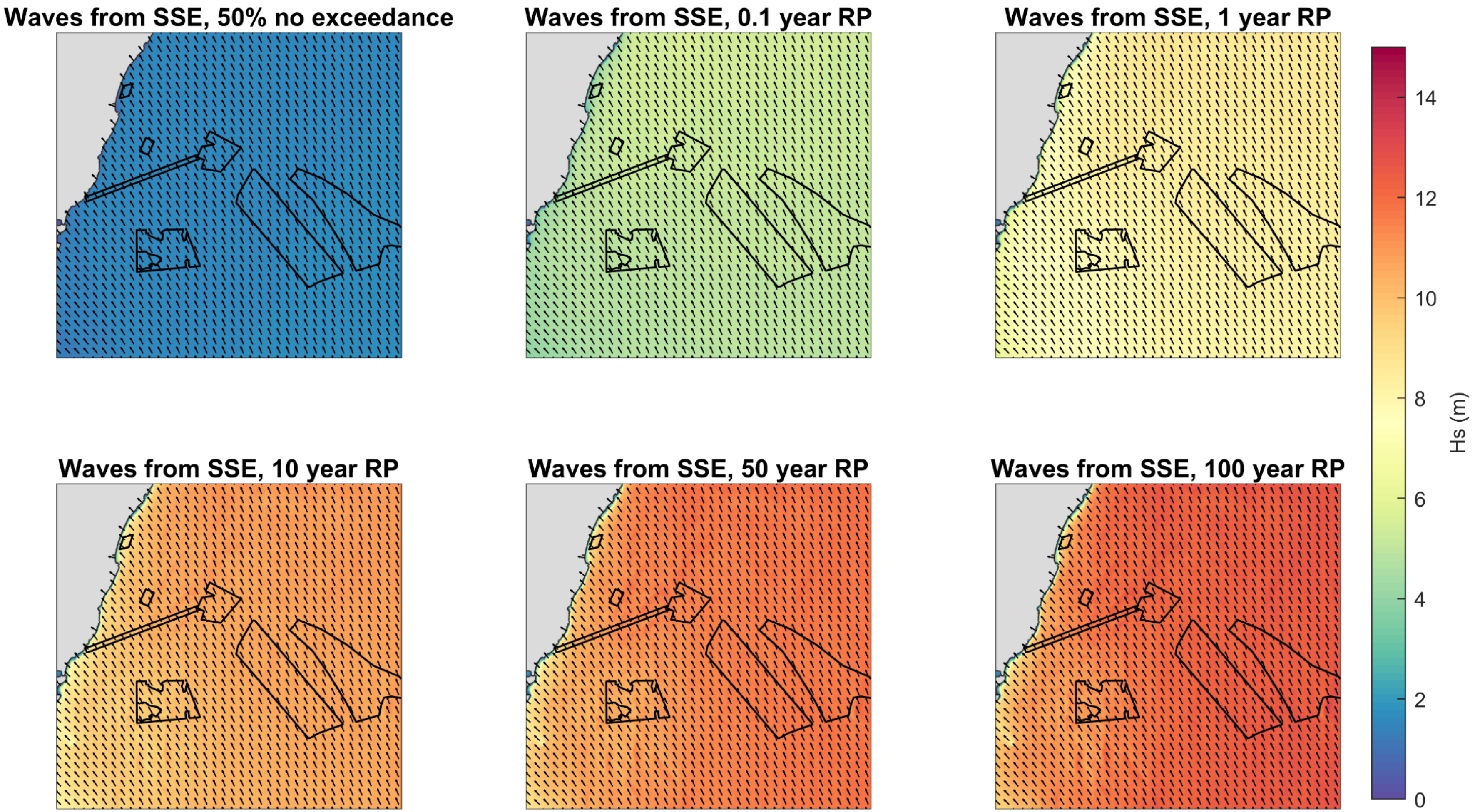
Pre-lay trenching during neaps
Release +3Days

Pre-lay trenching during springs
Release +3Days

The Morven North array area is outlined in black.

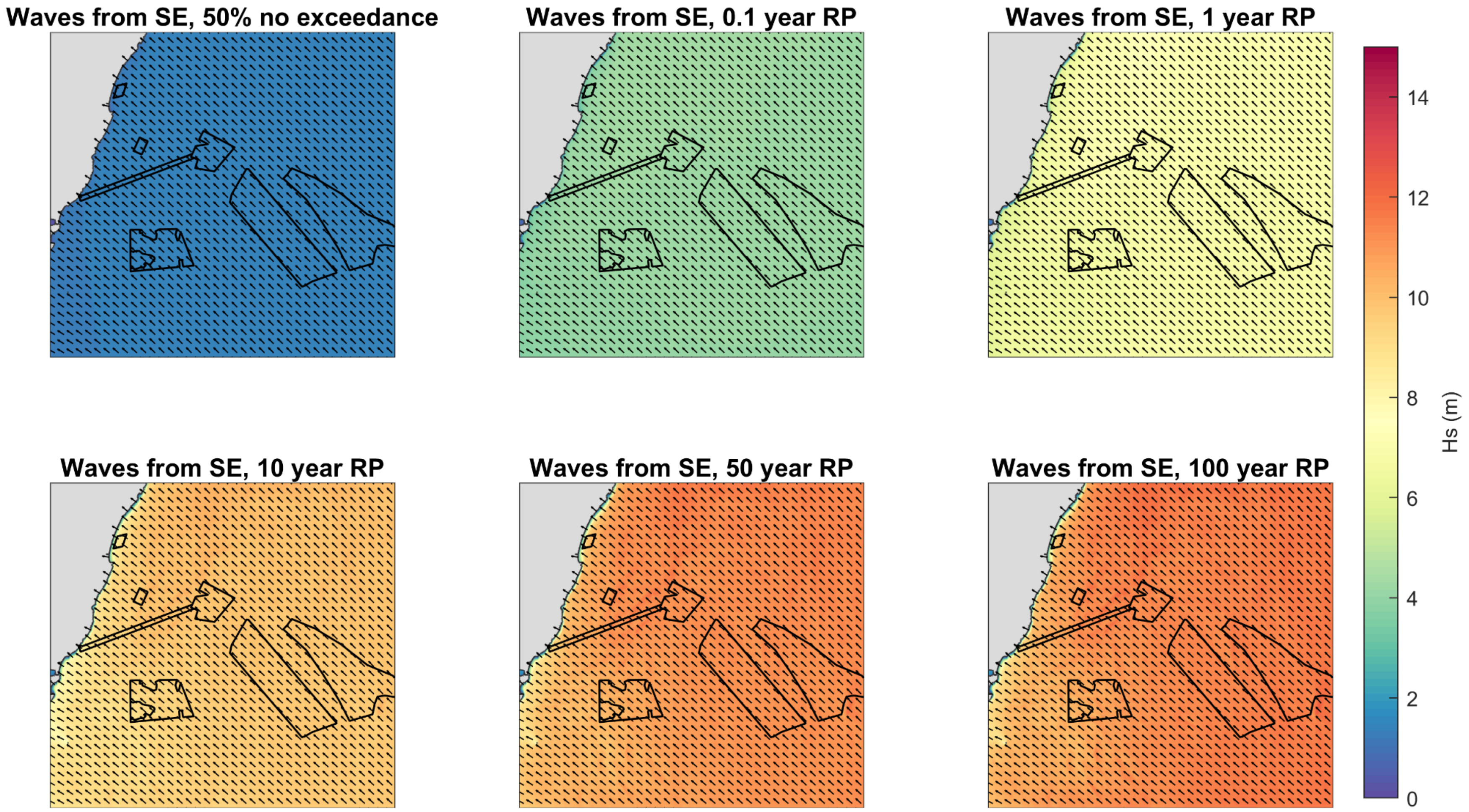
Figure B1.5: Sediment Settlement Thickness as a Result of Drilling a Pile, Sandwave Clearance via MFE and Spoil Release in the Morven North Array Area. Mean Spring (right) and Mean Neap (left) Tides

ANNEX C. WAVE MODEL BASELINE AND RESULTS FIGURES



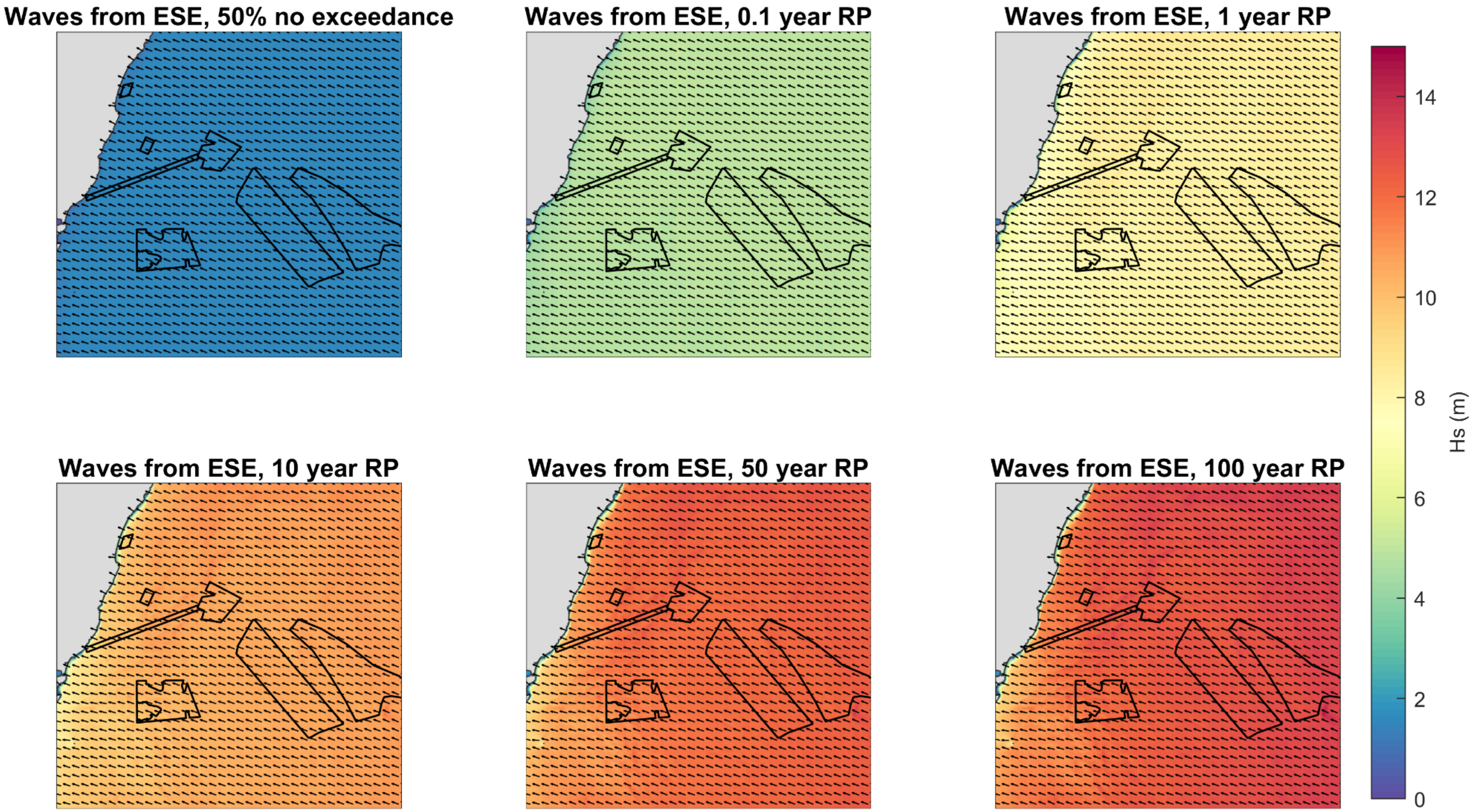
The Bowdun Array Area, Bowdun Export Cable Corridor and other OWFs included in the cumulative assessment are outlined in black.

Figure C1.1: Baseline Significant Wave Height, Waves From the South South-east, All Return Periods



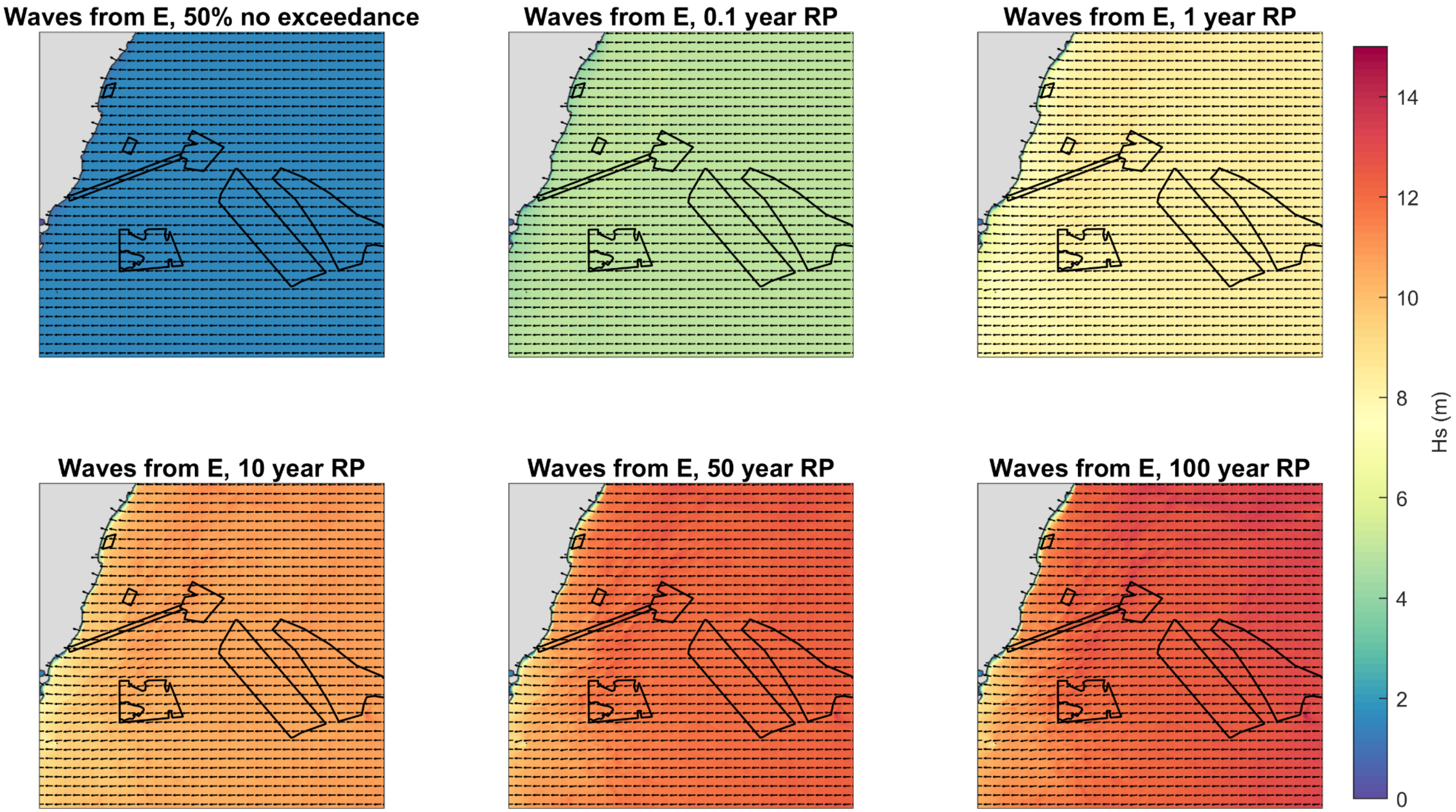
The Bowdun Array Area, Bowdun Export Cable Corridor and other OWFs included in the cumulative assessment are outlined in black.

Figure C1.2: Baseline Significant Wave Height, Waves From the South-east, All Return Periods



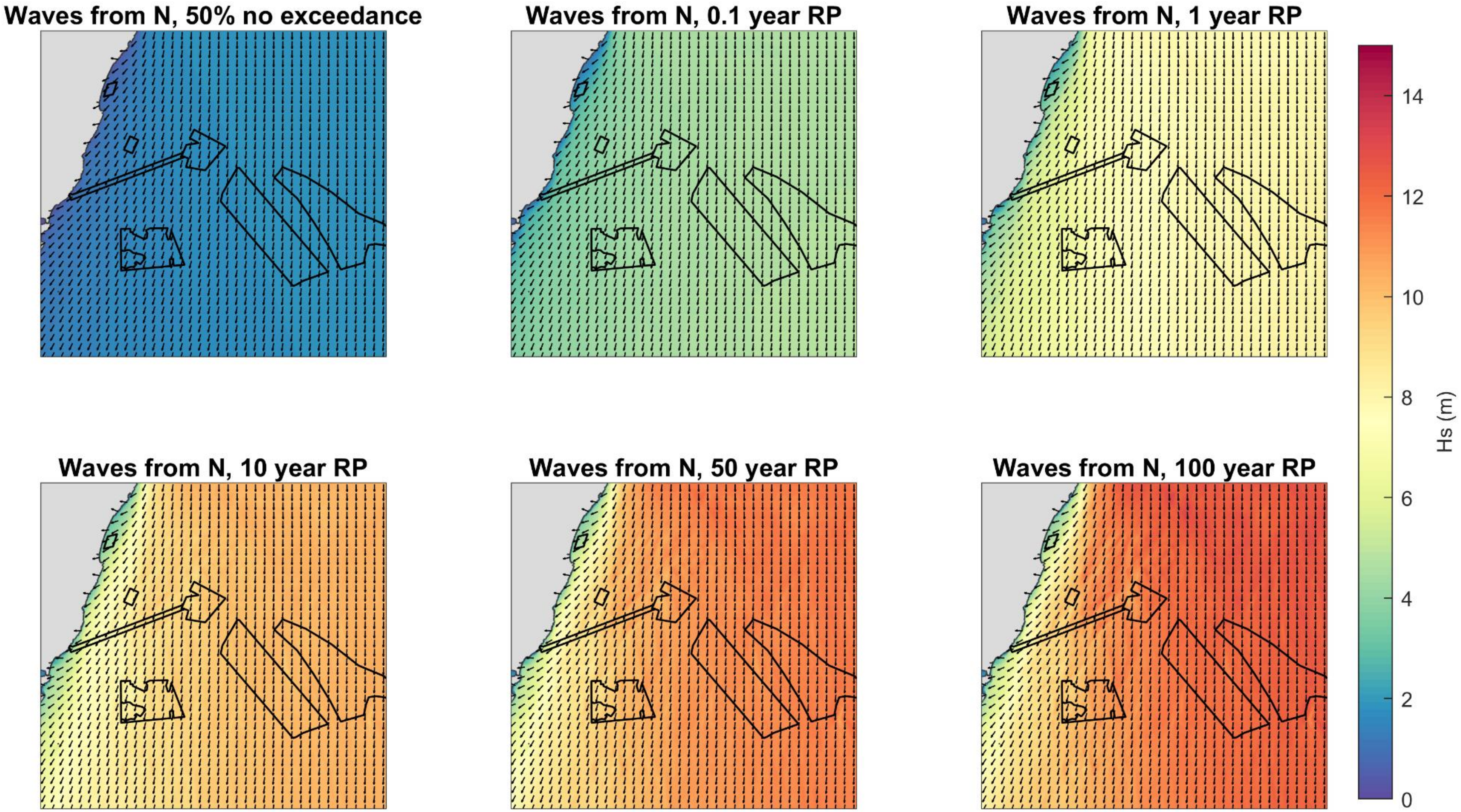
The Bowdun Array Area, Bowdun Export Cable Corridor and other OWFs included in the cumulative assessment are outlined in black.

Figure C1.3: Baseline Significant Wave Height, Waves From the East South-east, All Return Periods



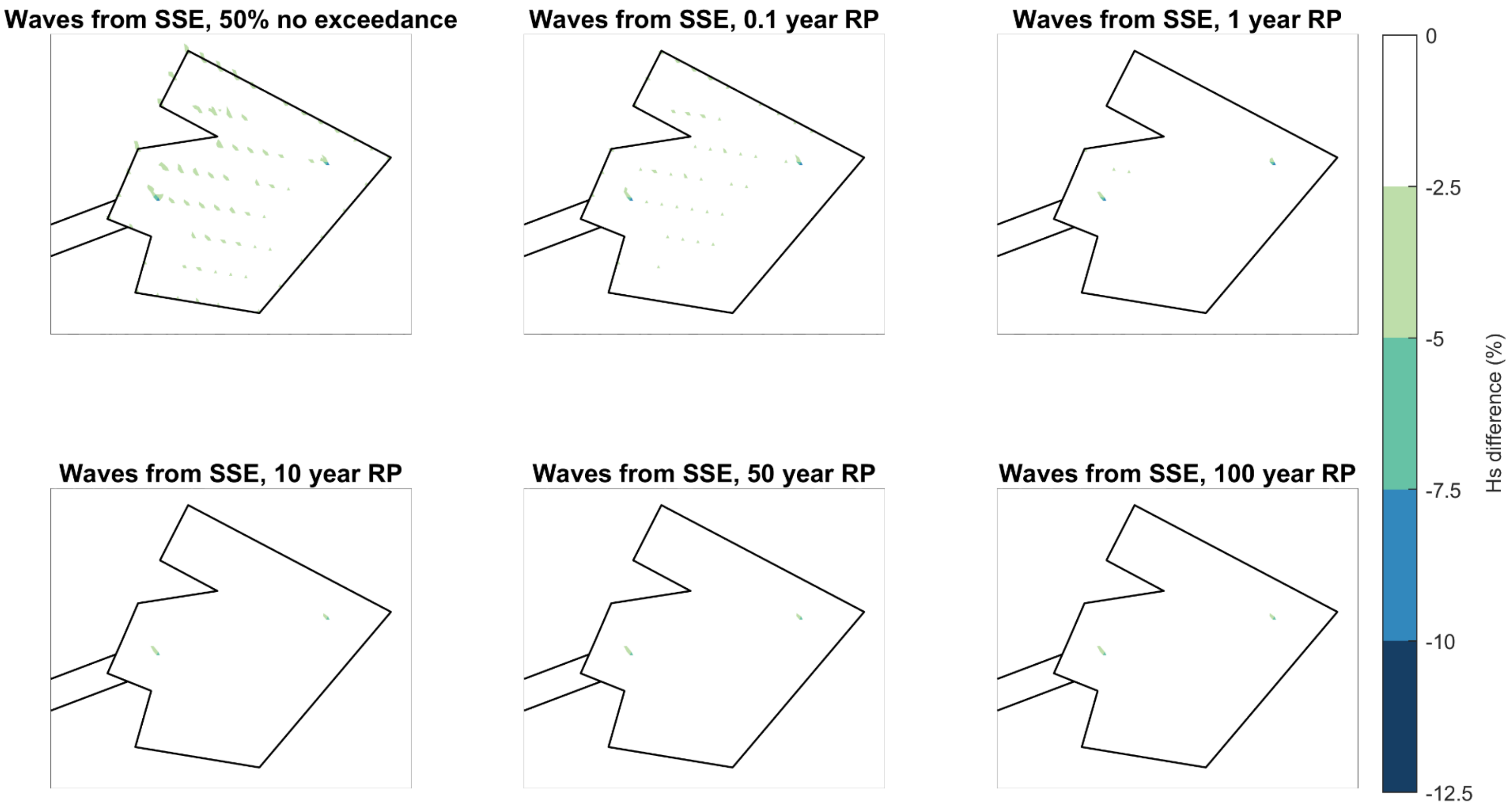
The Bowdun Array Area, Bowdun Export Cable Corridor and other OWFs included in the cumulative assessment are outlined in black.

Figure C1.4: Baseline Significant Wave Height, Waves From the East, All Return Periods



The Bowdun Array Area, Bowdun Export Cable Corridor and other OWFs included in the cumulative assessment are outlined in black.

Figure C1.5: Baseline Significant Wave Height, Waves From the North, All Return Periods

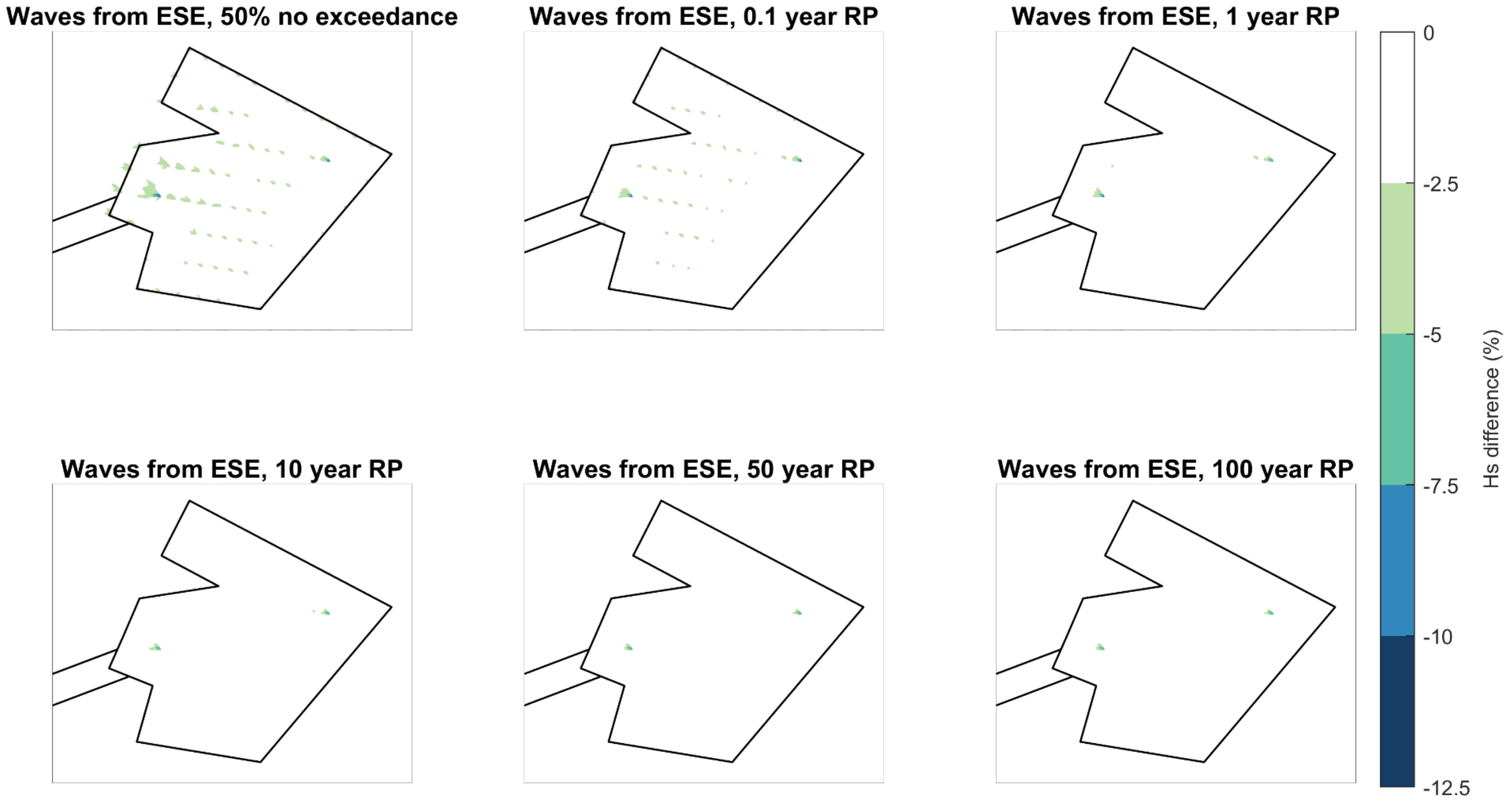


The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure.

Figure C1.6: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the South South-east, All Return Periods. MDS For Bowdun

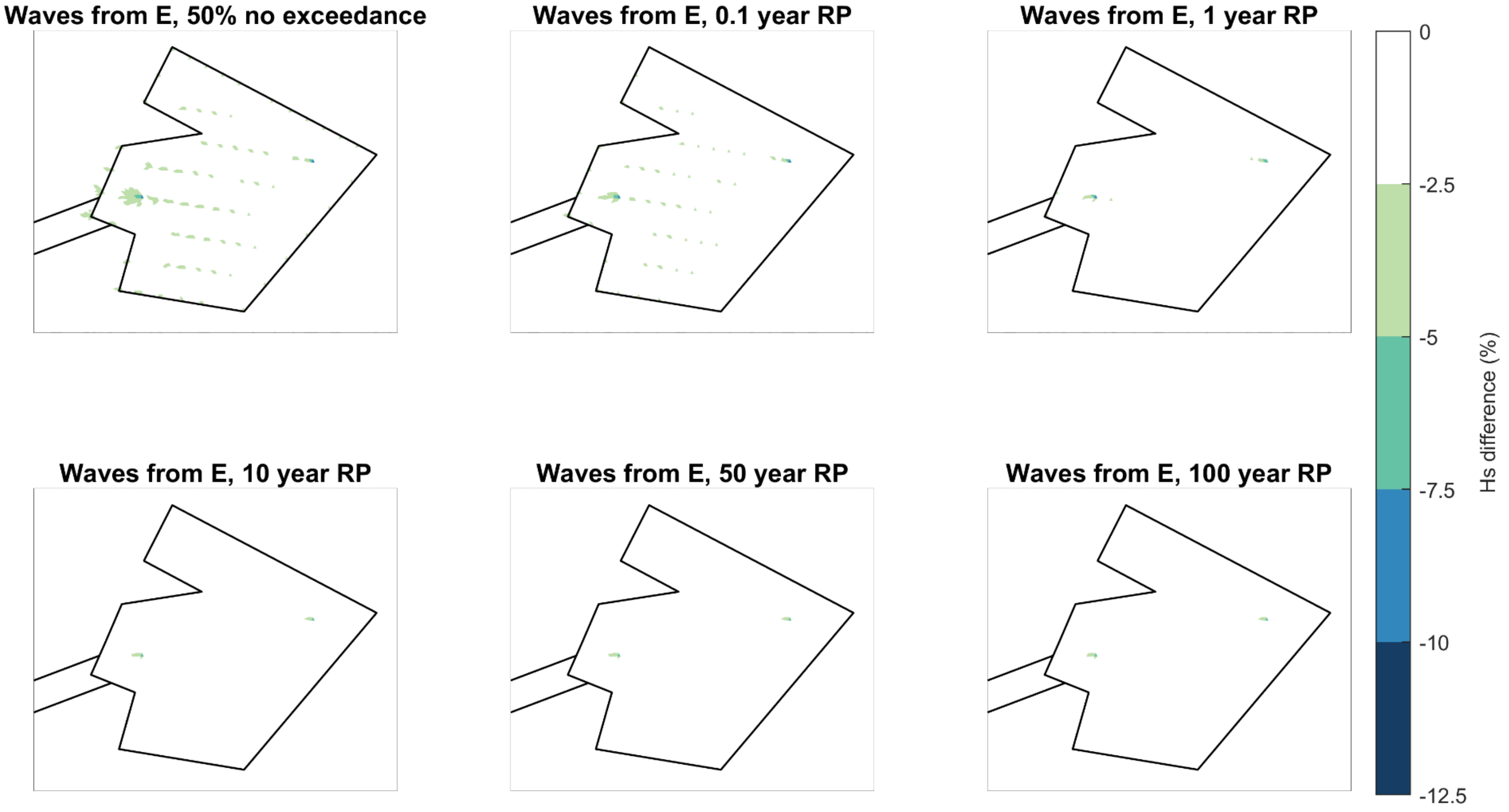
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure.

Figure C1.7: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the South-east, All Return Periods. MDS For Bowdun



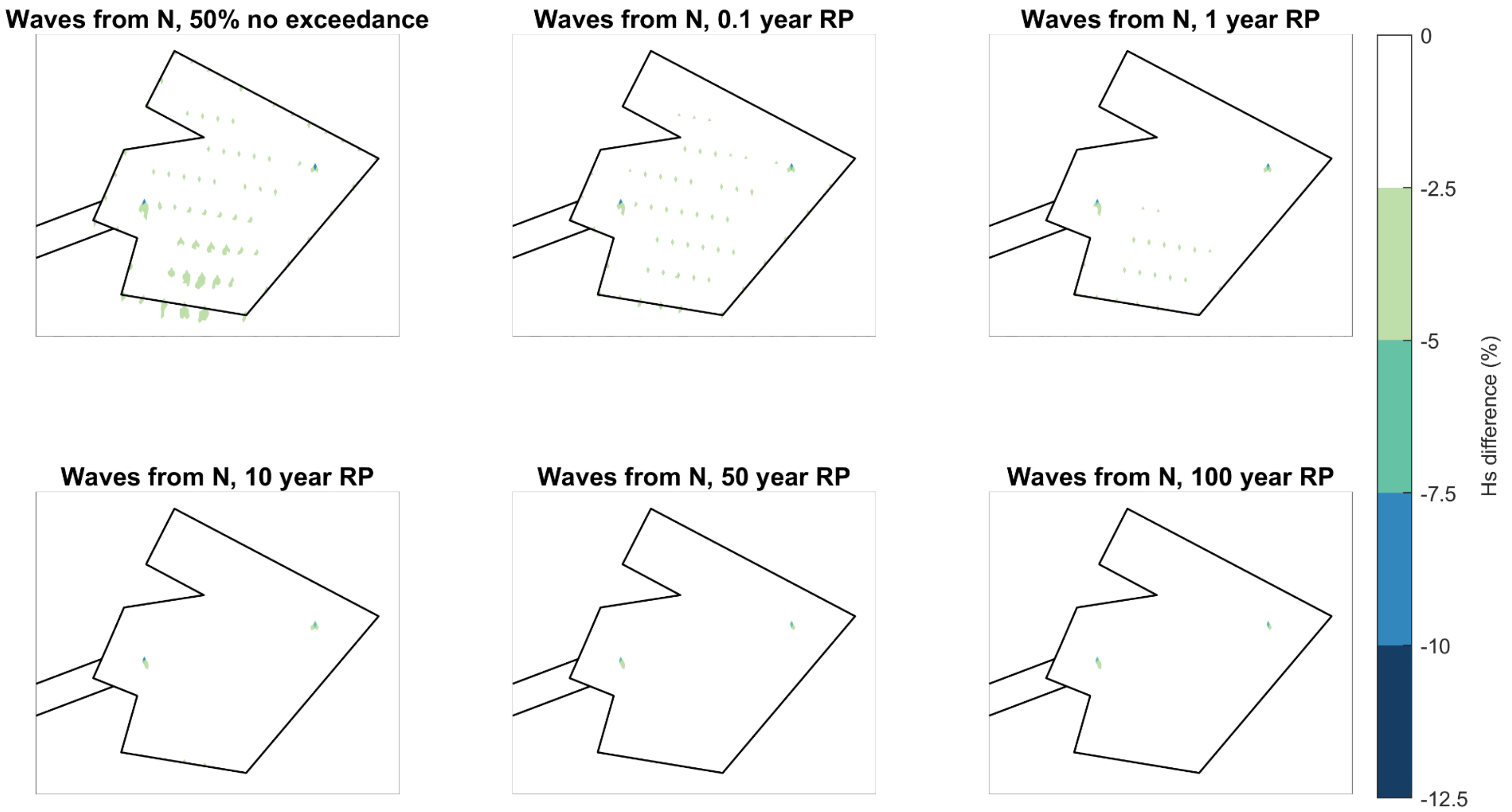
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure.

Figure C1.8: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the East South-east, All Return Periods. MDS For Bowdun



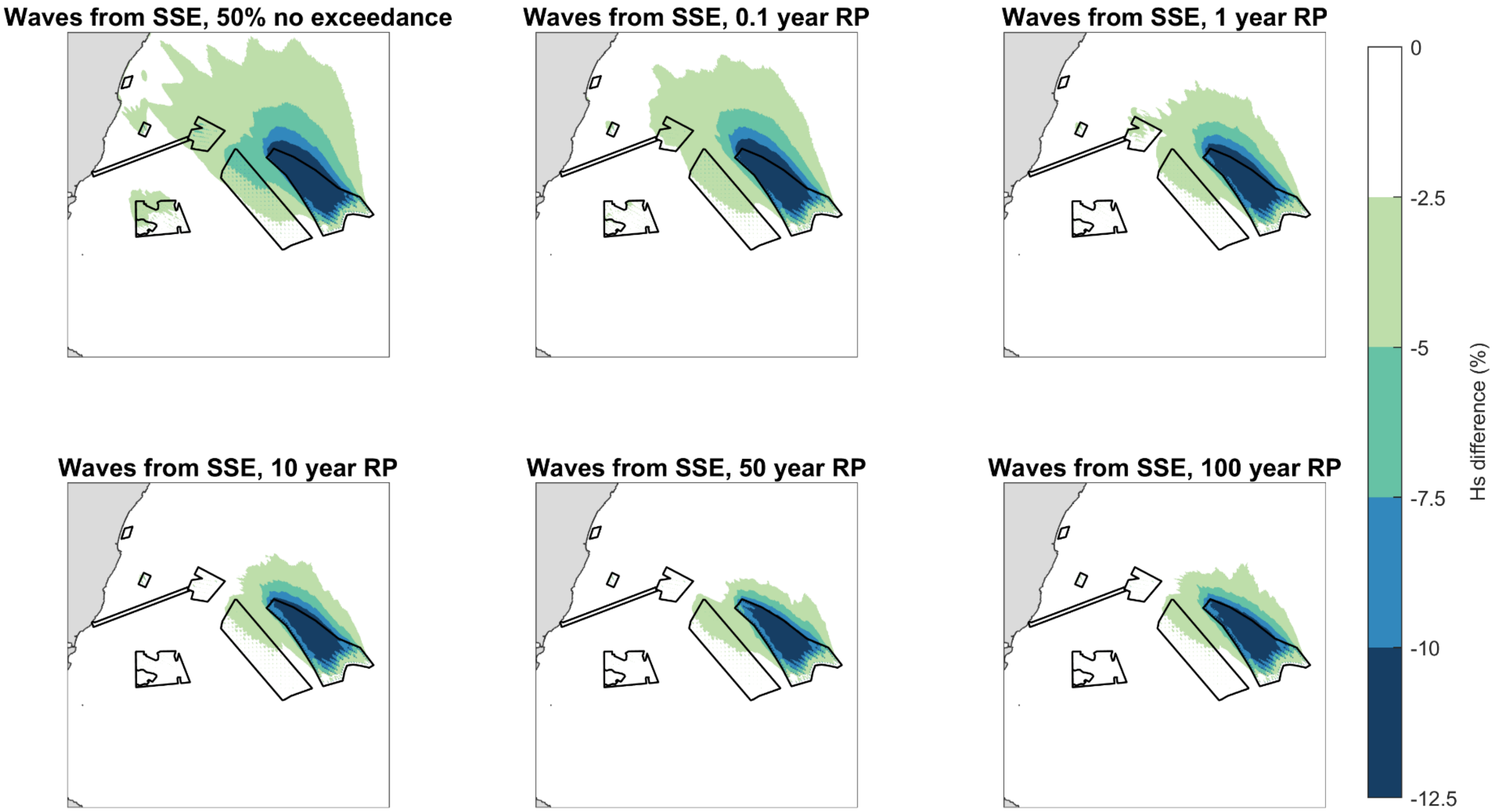
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure.

Figure C1.9: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the East, All Return Periods. MDS For Bowdun



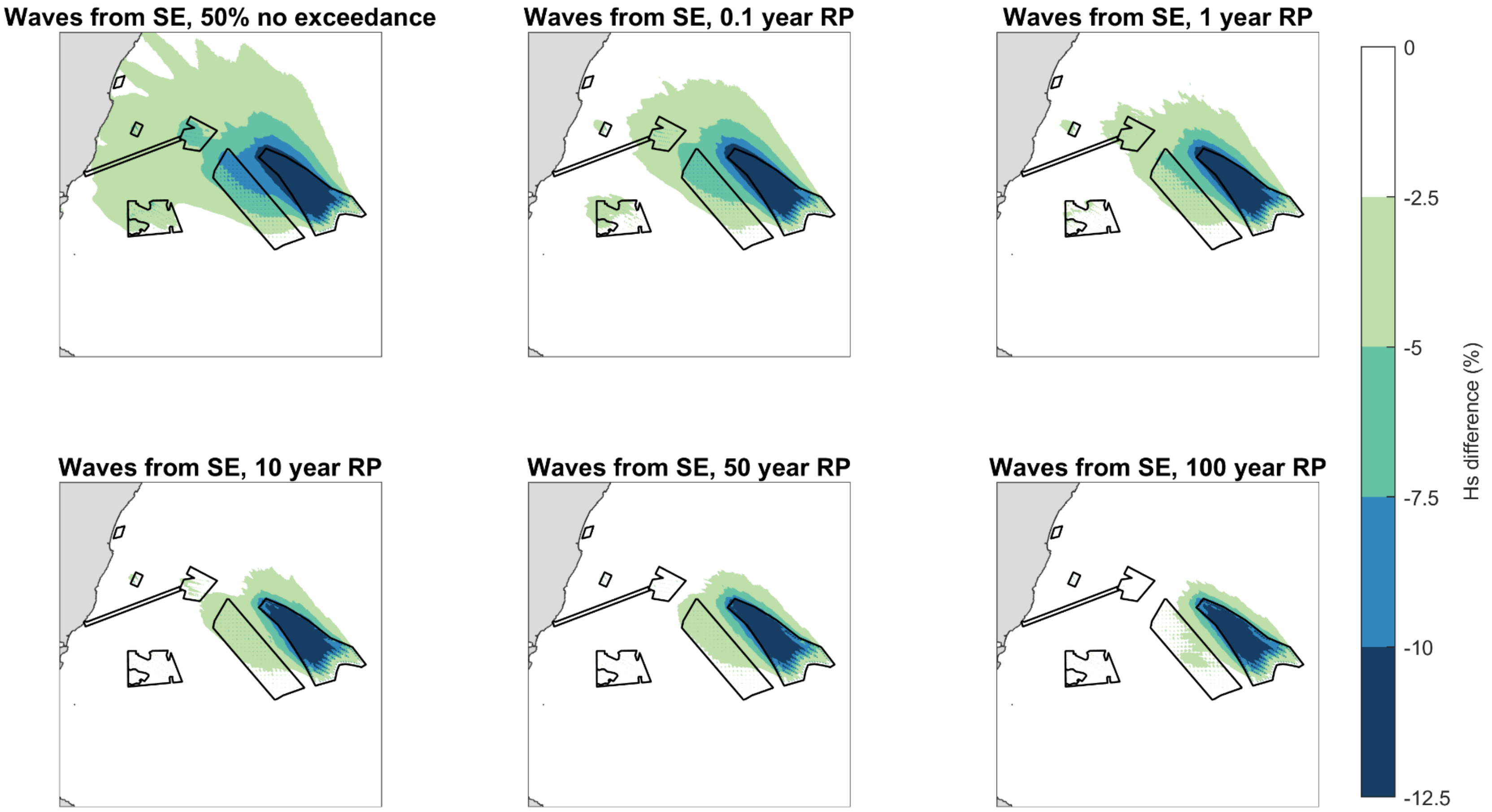
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure.

Figure C1.10: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the North, All Return Periods. MDS For Bowdun



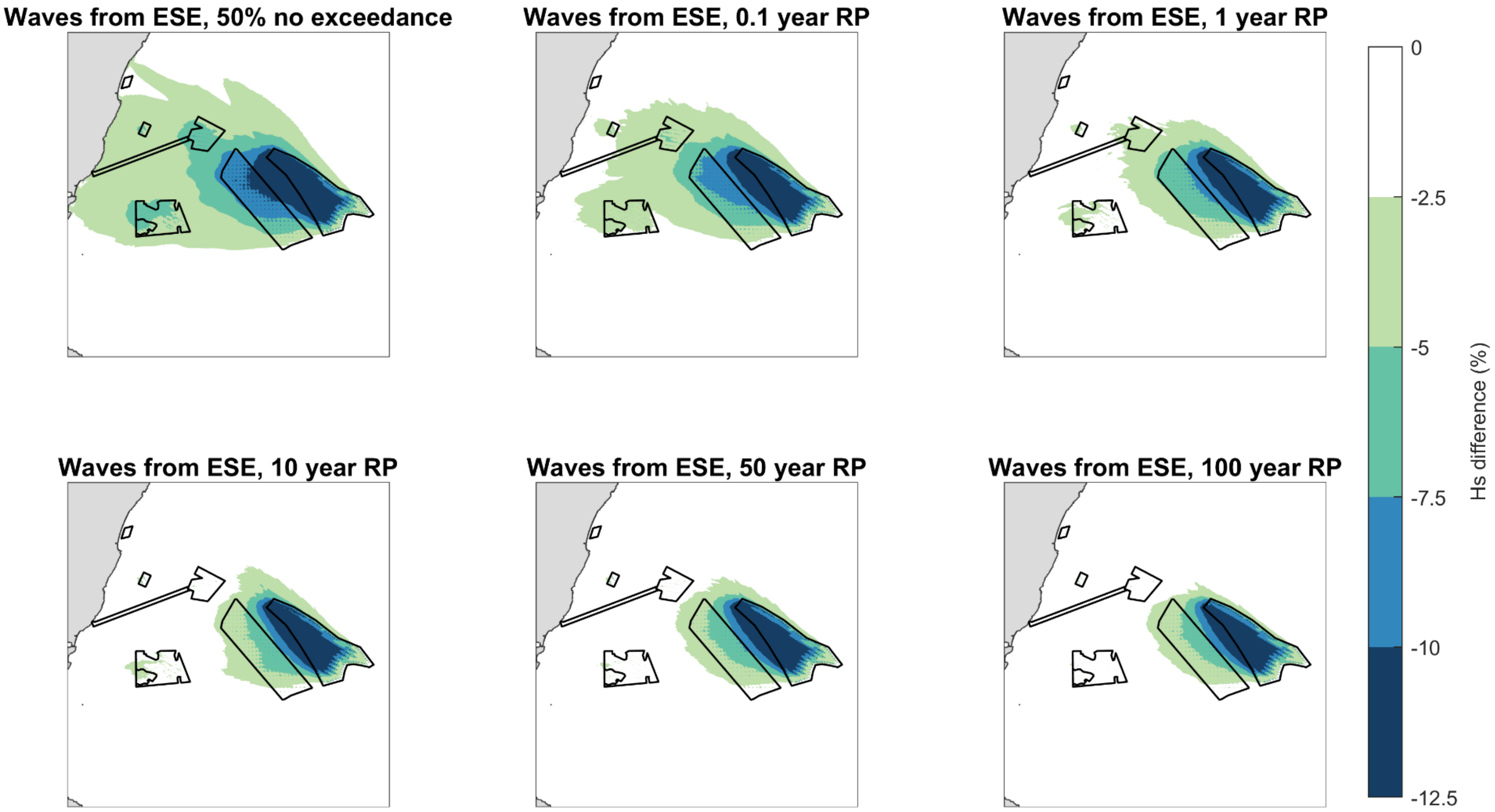
Array Areas are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure. The relatively large effect of Ossian OWF is the result of conservative representation of MDS floater dimensions and number.

Figure C1.11: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the South South-east, All Return Periods. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



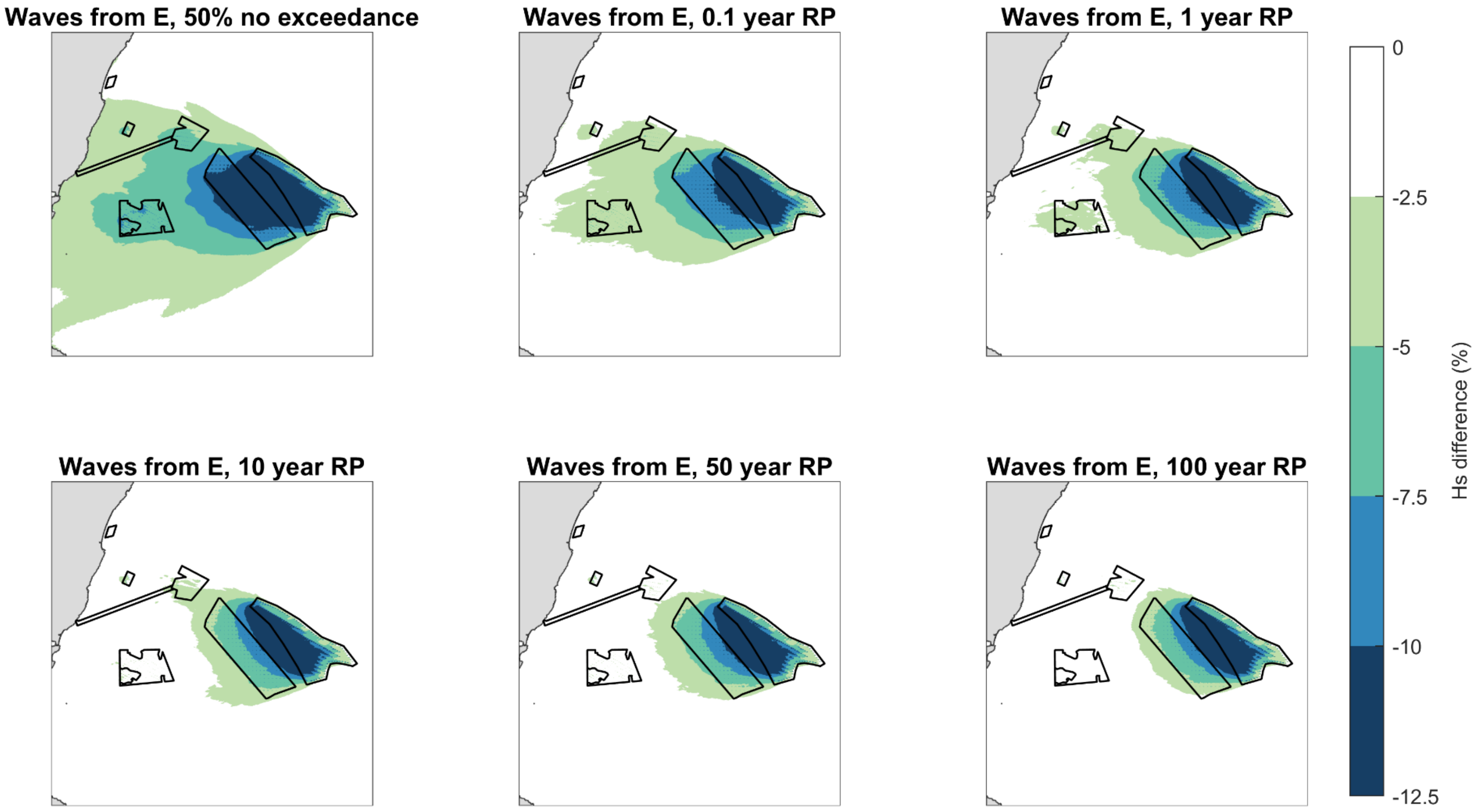
Array Areas are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure. The relatively large effect of Ossian OWF is the result of conservative representation of MDS floater dimensions and number.

Figure C1.12: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the South-east, All Return Periods. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



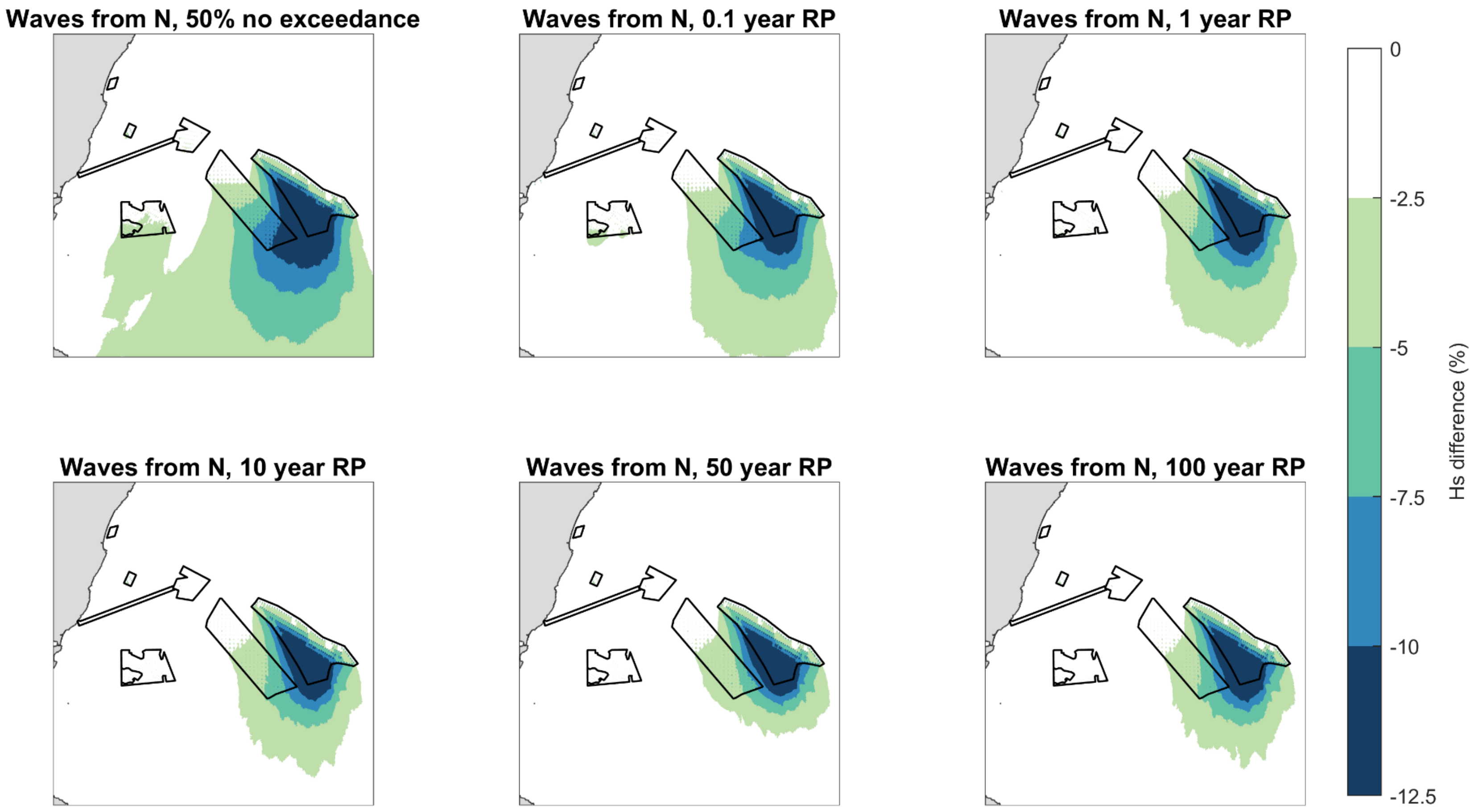
Array Areas are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure. The relatively large effect of Ossian OWF is the result of conservative representation of MDS floater dimensions and number.

Figure C1.13: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the East South-east, All Return Periods. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



Array Areas are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure. The relatively large effect of Ossian OWF is the result of conservative representation of MDS floater dimensions and number.

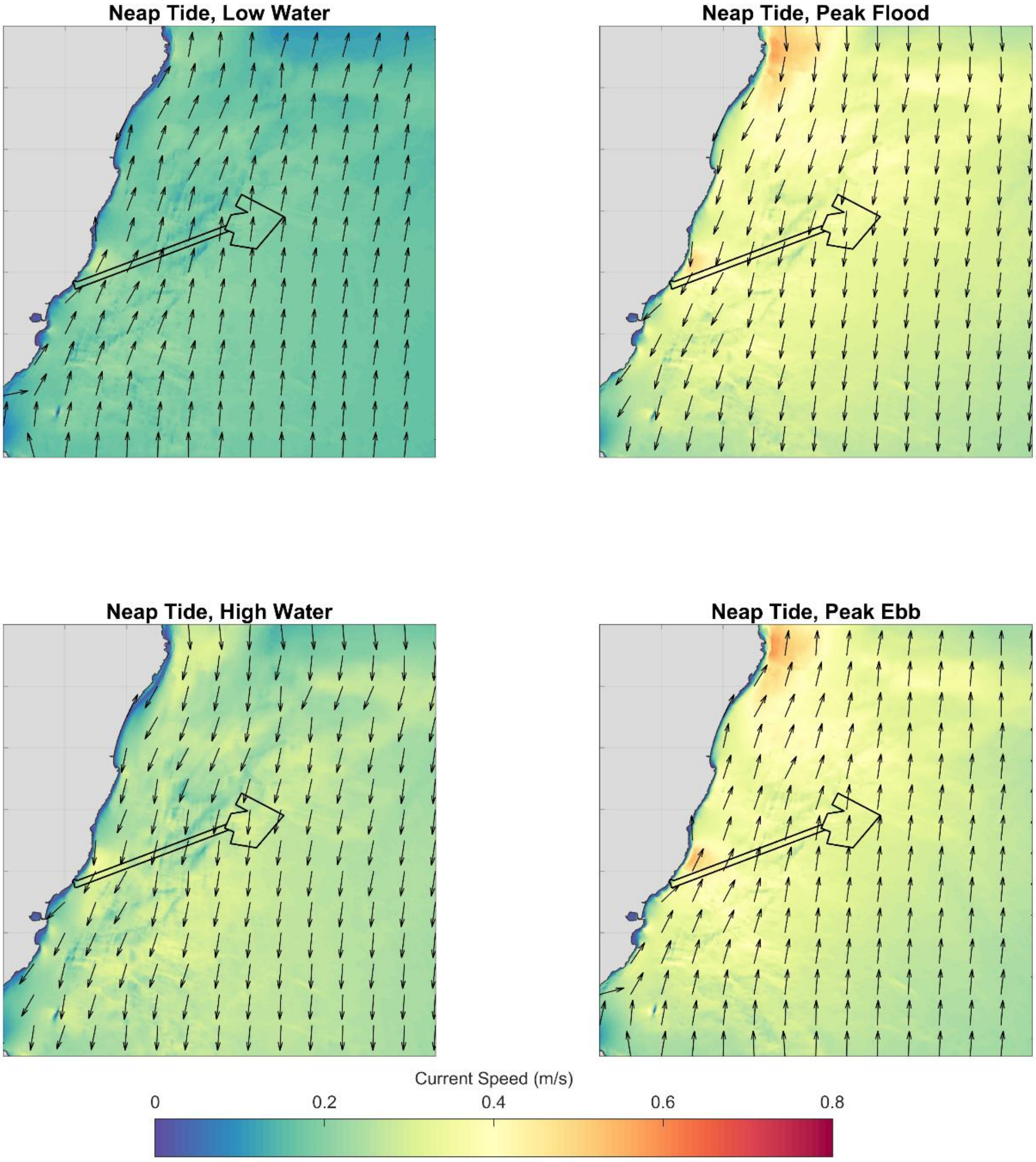
Figure C1.14: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the East, All Return Periods. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



Array Areas are outlined in black. Negative Values are a Reduction in Wave Height as a Result of the Installed Infrastructure. The relatively large effect of Ossian OWF is the result of conservative representation of MDS floater dimensions and number.

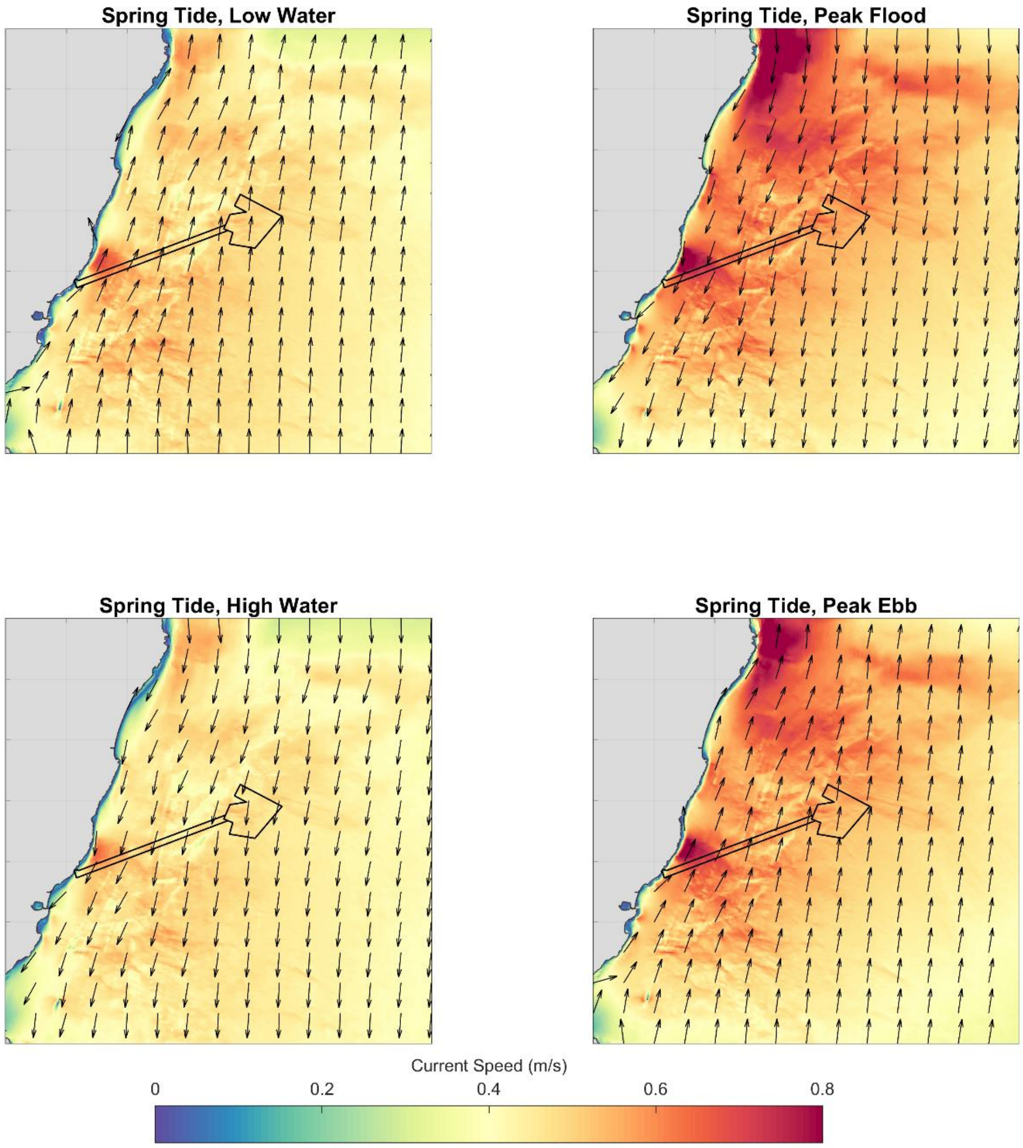
Figure C1.15: Percentage Difference in Significant Wave Height (Scheme Minus Baseline as a Proportion of Baseline Values), Operational Phase, Waves From the North, All Return Periods. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms

ANNEX D. TIDAL MODEL BASELINE AND RESULTS FIGURES



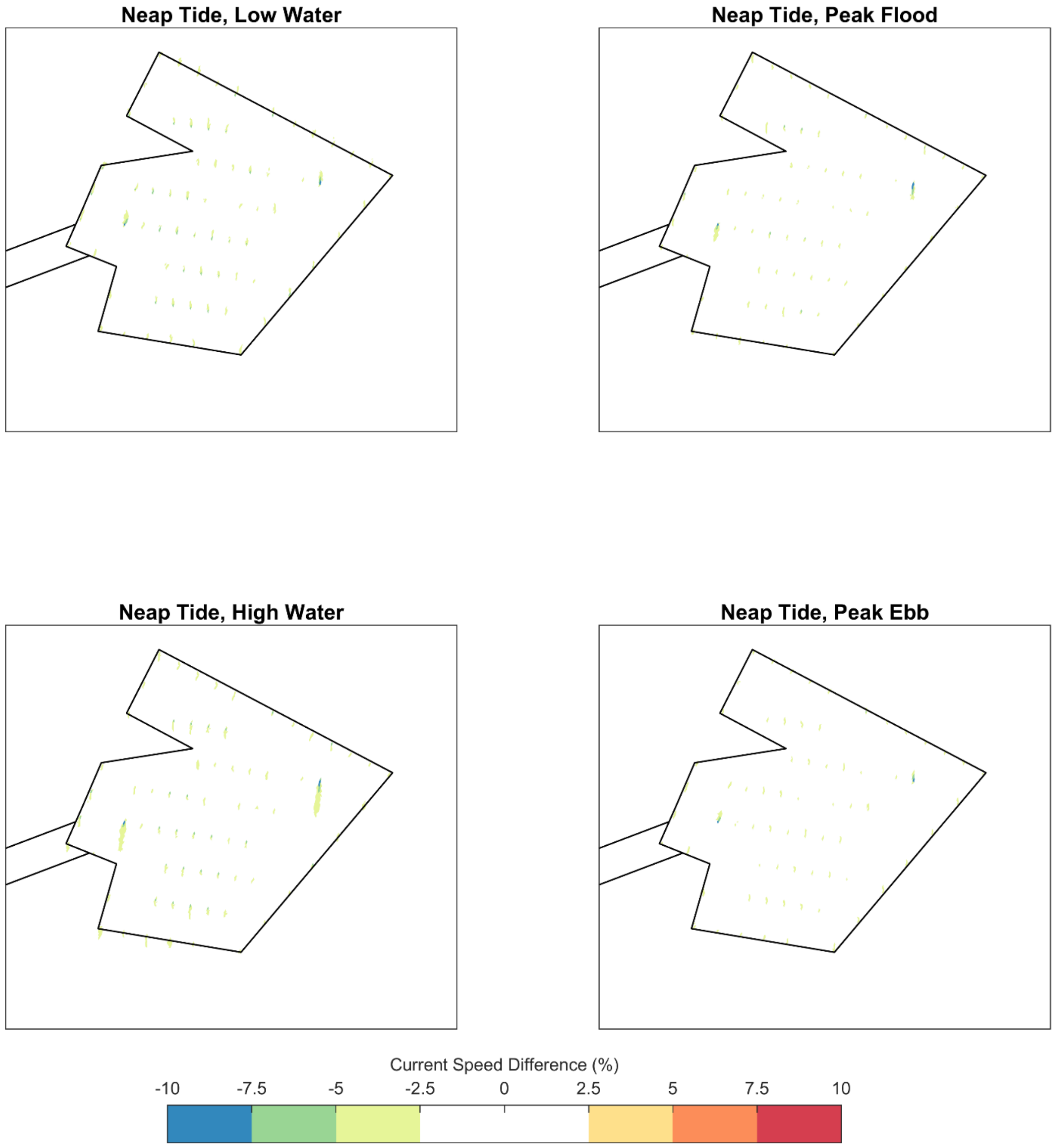
The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.1: Baseline Tidal Current Speed and Direction During a Representative Neap Tidal Condition



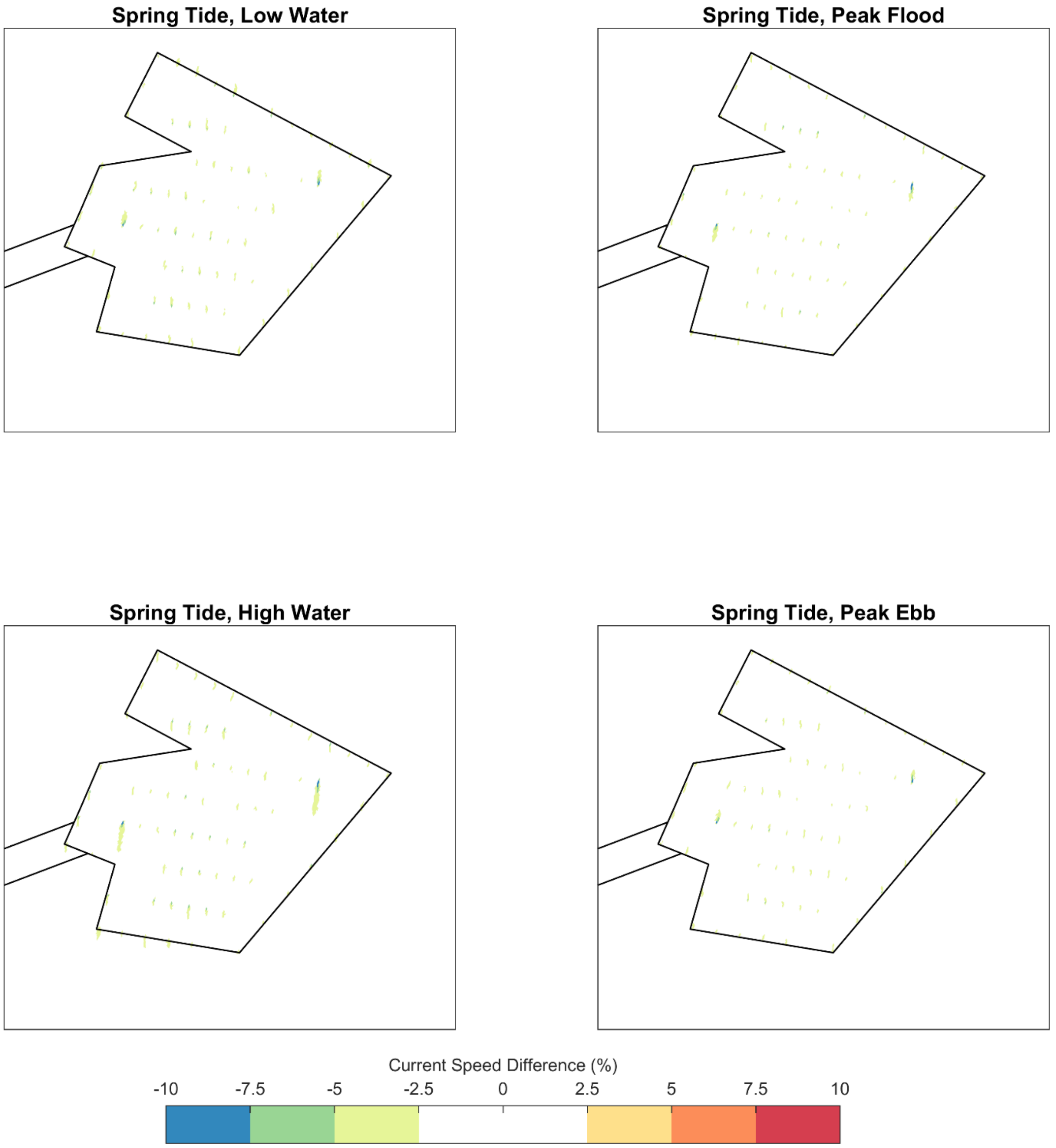
The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.2: Baseline Tidal Current Speed and Direction During a Representative Spring Tidal Condition



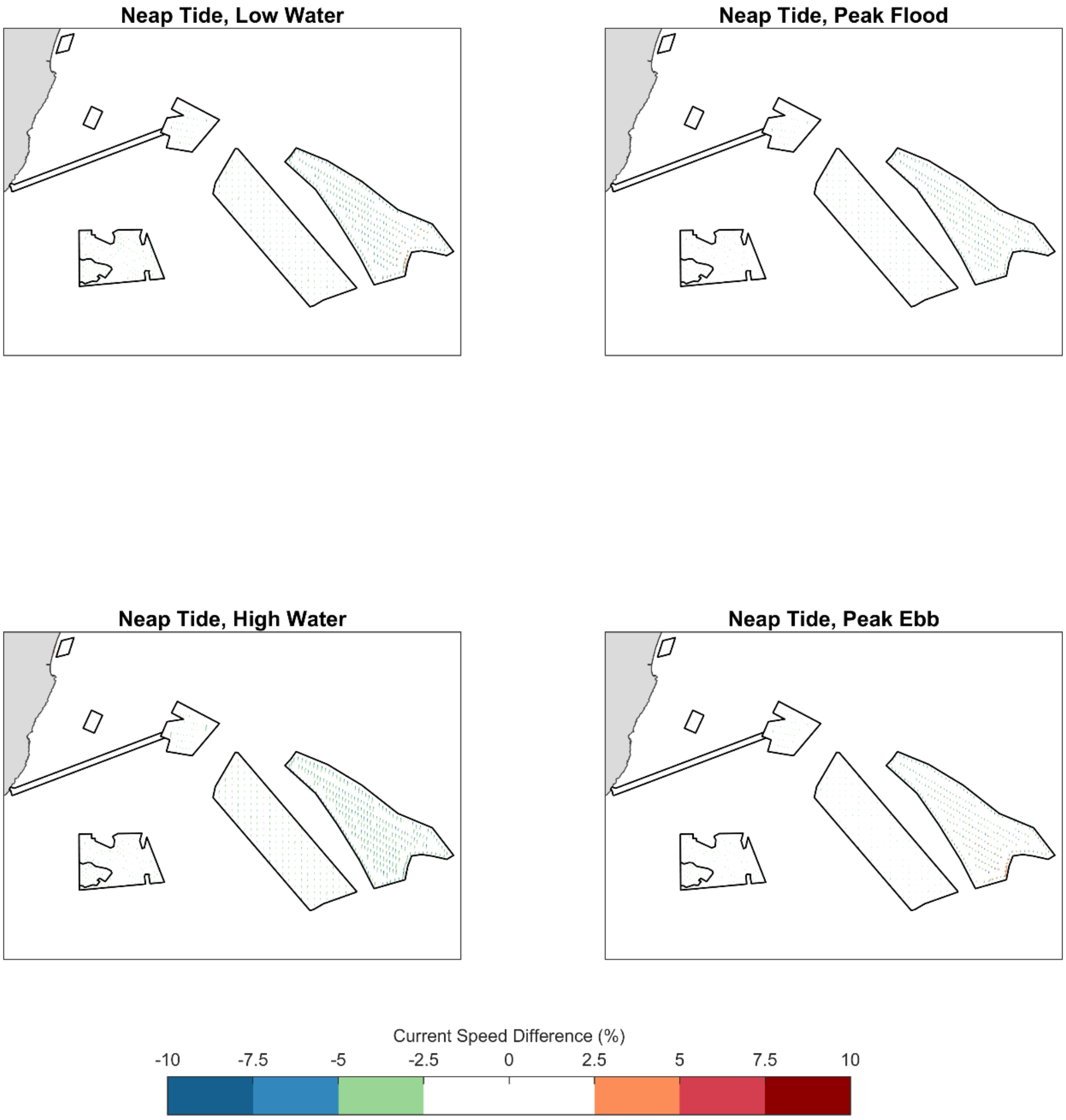
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative and Positive Values are a Reduction or Increase in Time Average Current Speed, Respectively.

Figure D1.3: Percentage Difference in Tidal Current Speed (Scheme Minus Baseline), Operational Phase, During a Representative Neap Tidal Condition. MDS For Bowdun



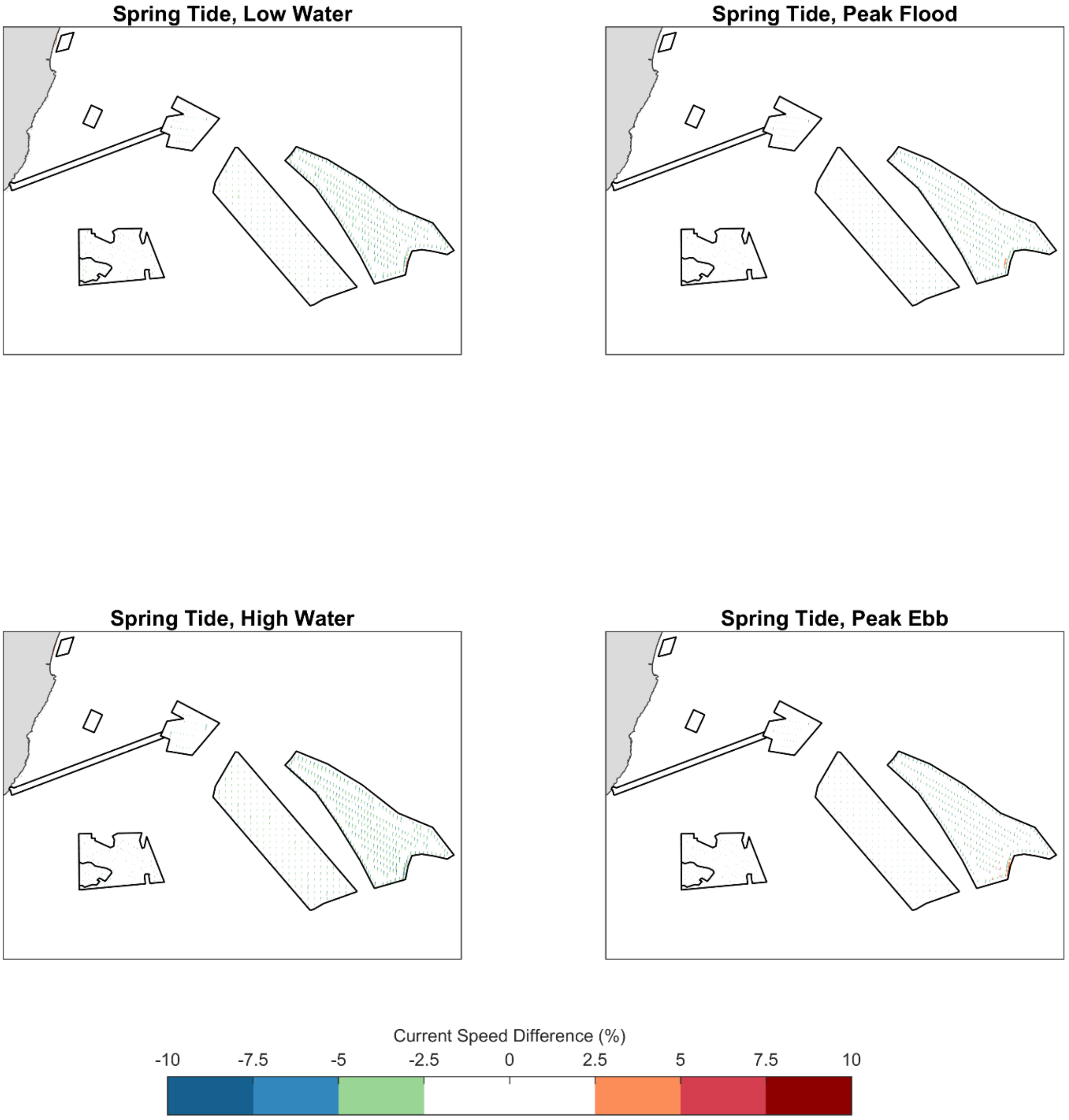
The Bowdun Array Area and Export Cable Corridor are outlined in black. Negative and Positive Values are a Reduction or Increase in Time Average Current Speed, Respectively.

Figure D1.4: Percentage Difference in Tidal Current Speed (Scheme Minus Baseline), Operational Phase, During a Representative Spring Tidal Condition. MDS For Bowdun



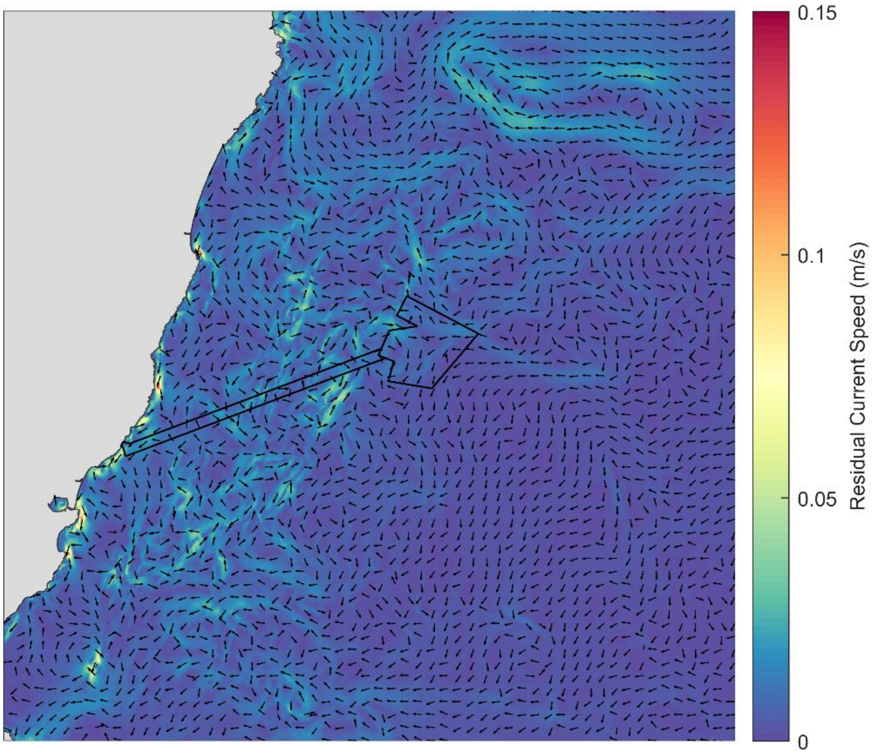
Array Areas are outlined in black. Negative and Positive Values are a Reduction or Increase in Time Average Current Speed, Respectively.

Figure D1.5: Percentage Difference in Tidal Current Speed (Scheme Minus Baseline), Operational Phase, During a Representative Neap Tidal Condition. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



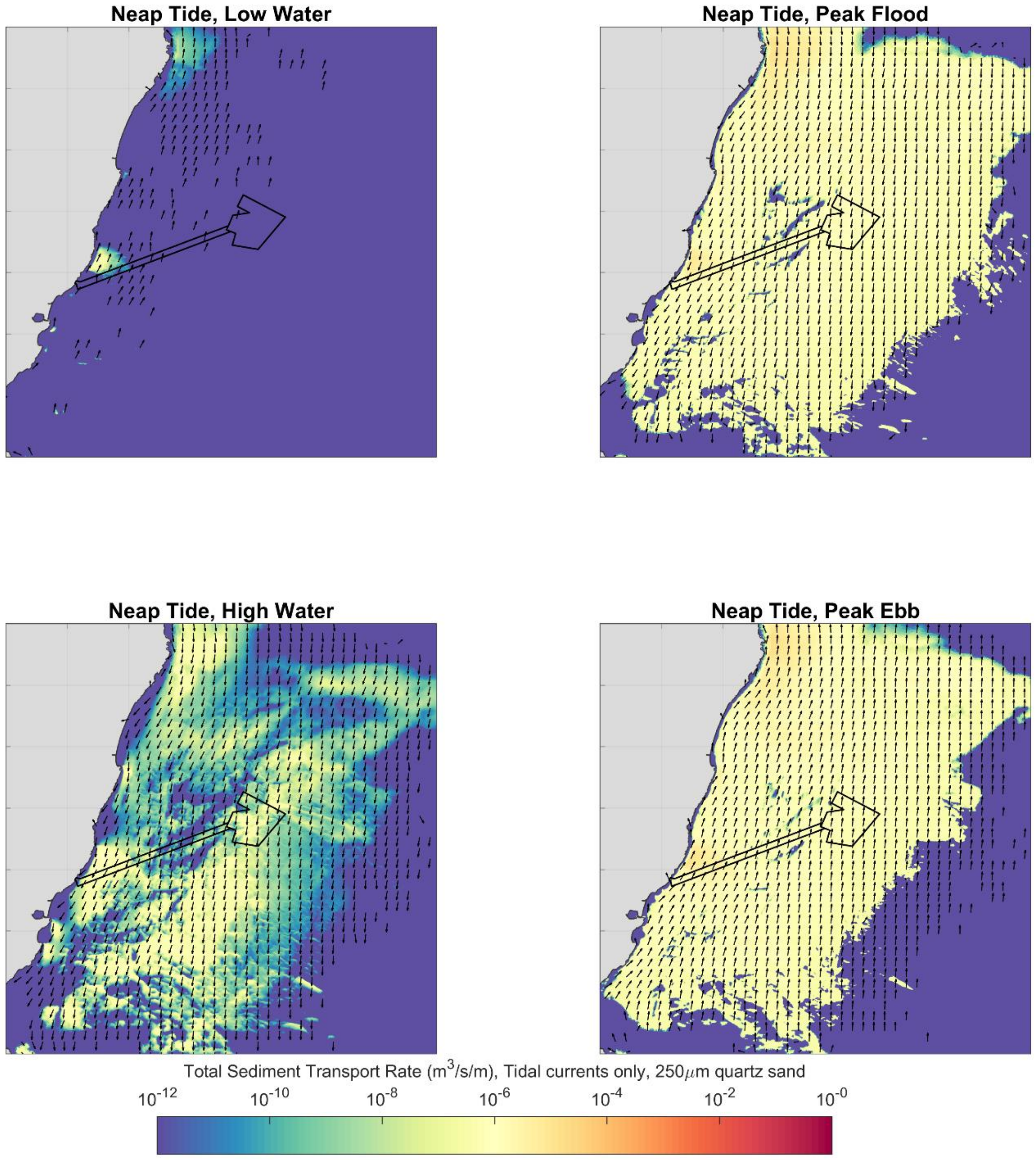
Array Areas are outlined in black. Negative and Positive Values are a Reduction or Increase in Time Average Current Speed, Respectively.

Figure D1.6: Percentage Difference in Tidal Current Speed (Scheme Minus Baseline), Operational Phase, During a Representative Spring Tidal Condition. MDS For Bowdun and Other Existing and Planned Offshore Wind Farms



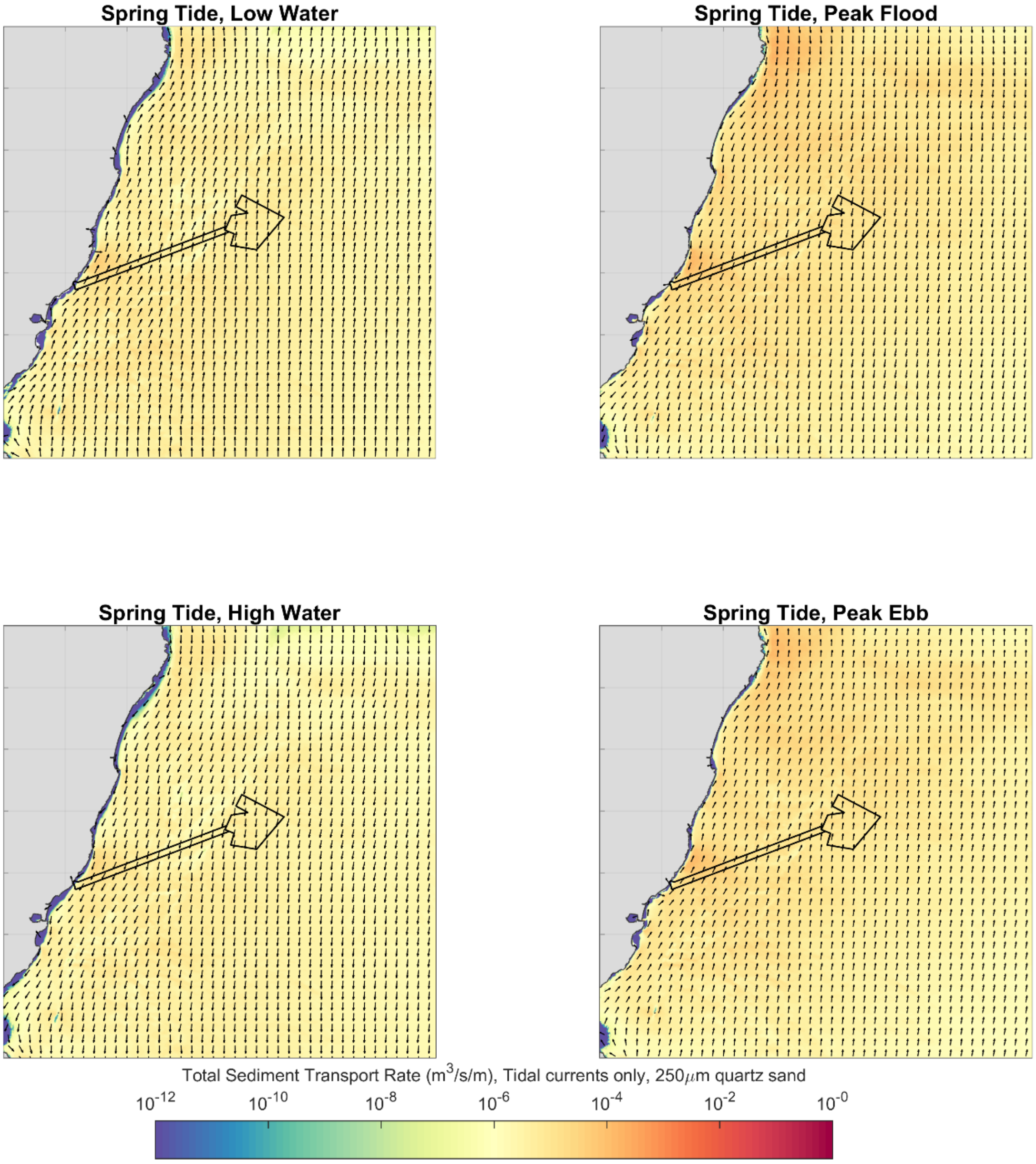
The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.7: Baseline Residual Tidal Current Speed and Direction Over a Representative Spring-Neap Tidal Period



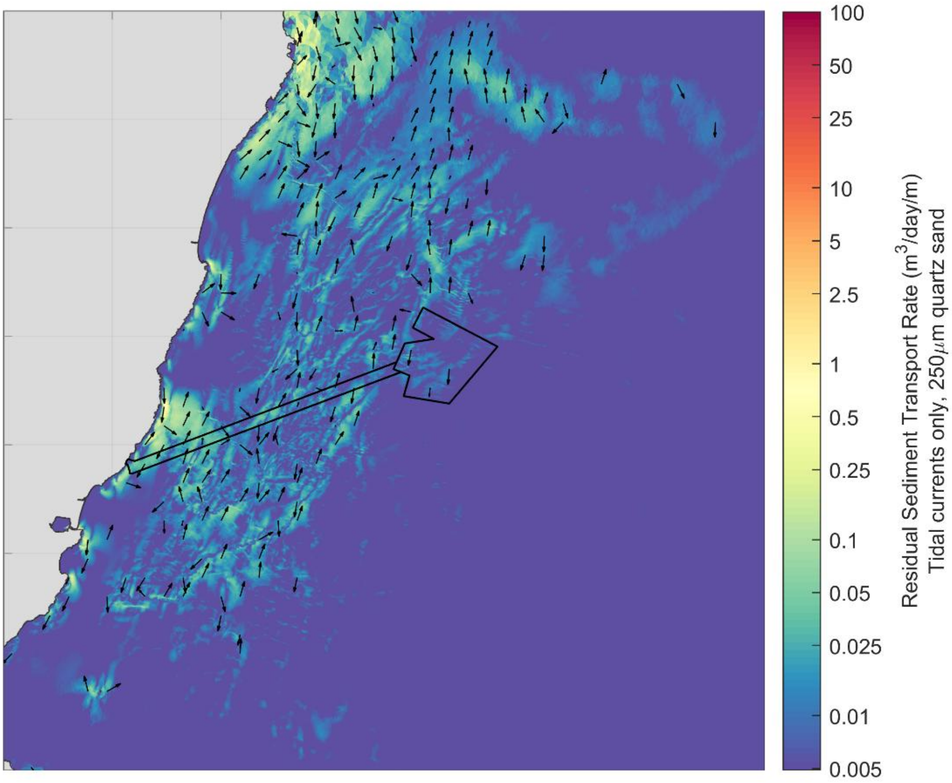
The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.8: Baseline Sediment Transport Rate and Direction, for 250 µm Quartz Sand, During a Representative Neap Tidal Condition



The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.9: Baseline Sediment Transport Rate and Direction, for 250 µm Quartz Sand, During a Representative Spring Tidal Condition



The Bowdun Array Area and Export Cable Corridor are outlined in black.

Figure D1.10: Baseline Residual Sediment Transport Rate and Direction, for 250 µm Quartz Sand, Predicted Over a Representative Spring-Neap Tidal Period

ANNEX E. SCOUR CALCULATIONS

E1 Overview

E1.1.1 In order to quantify the area of seabed that might be affected by scour (either the footprint of scour or scour protection), estimates of the theoretical maximum depth and extent of scour are provided below. Estimates are made of the primary scour, (i.e. the scour pit directly associated with the presence of the main obstacle).

E1.1.2 The equilibrium primary scour depth for each foundation type has been conservatively calculated assuming the absence of any scour protection, using empirical relationships described in Whitehouse (1998). This analysis considers scour resulting from the characteristic wave and current regime, both alone and in combination.

E1.1.3 The project description provides MDS extents of scour protection for each foundation type. Scour protection might be applied around the base of some or all foundations depending upon the seabed conditions and other engineering requirements. By design, scour protection will largely prevent the development of primary scour but may itself cause smaller scale secondary scour due to turbulence at the edges of the scour protection area.

E2 Assumptions

E2.1.1 The following scour assessment for the Proposed Development reports the estimated equilibrium scour depth, which assumes that there are no limits to the depth or extent of scour development by time or the nature of the sedimentary or metocean environments. As such, the results of this study are considered to be conservative and provide an (over-) estimation of the maximum potential scour depth, footprint and volume. Several factors may naturally reduce or restrict the equilibrium scour depth locally, with a corresponding reduction in the area and volume of change.

E2.1.2 This study makes the basic assumption that the seabed comprises an unlimited thickness of uniform non-cohesive and easily eroded sediment. In practice the thickness of more easily erodible surficial sediment is spatially variable across the Array Area, typically 0 to 2 m thick (G-tec, 2025a).

E2.1.3 The foundation types, dimensions and numbers used in the assessment are consistent with the project design information.

E2.1.4 Reported observations of scour under steady current conditions (e.g. in rivers) generally show that the upstream slope of the depression is typically equal to the angle of internal friction for the exposed sediment (typically 32° in loose medium sand; Hoffmans and Verheil, 1997) but the downstream slope is typically less steep.

E2.1.5 In reversing (tidal) current conditions, both slopes will develop under alternating upstream and downstream forcing and so will tend towards the less steep or an intermediate condition. For the purposes of the present study a representative angle of internal friction (32°) will be used as the characteristic slope angle for scour development.

E3 Equilibrium Scour Depth

E3.1.1 The maximum equilibrium scour depth (Se) is defined as the depth of the scour pit adjacent to the structure, below the mean ambient or original seabed level. The value of Se is typically proportional to the diameter of the structure and so is commonly expressed in units of structure diameter (D).

E3.1.2 Scour depth decreases with distance from the edge of the foundation. The scour extent (S_{extent}) is defined as the radial distance from the edge of the structure (and the point of maximum scour depth) to the edge of the scour pit (where the bed level is again equal to the mean ambient or original seabed level). This is calculated on the basis of a linear slope at the angle of internal friction for the sediment:

$$S_{extent} = \frac{S_e}{\tan 32} \approx S_e \times 1.6$$

Equation 1

E3.1.3 The scour footprint ($S_{footprint}$) is defined as the seabed area affected by scour, excluding the foundation's footprint:

$$S_{footprint} = \pi\left(S_{extent} + \left(\frac{D}{2}\right)\right)^2 - \pi\left(\frac{D}{2}\right)^2$$

Equation 2

E3.1.4 The scour pit volume is calculated as the volume of an inverted truncated cone described by Equations 1 and 2 above, accounting for the presence of the foundation but excluding its volume.

E4 Scour Assessment Method: Wind Turbine Monopiles

E4.1.1 Compared to other more complex foundation types, scour around upright slender monopile structures (Figure E5.2) in steady currents is relatively well-understood in the literature and is supported by a relatively large empirical evidence base from the laboratory and from the field. The maximum equilibrium scour depth, adjacent to the structure, below the mean seabed level (Sc), is typically proportional to the diameter of the monopile and is therefore expressed in units of monopile diameter (D).

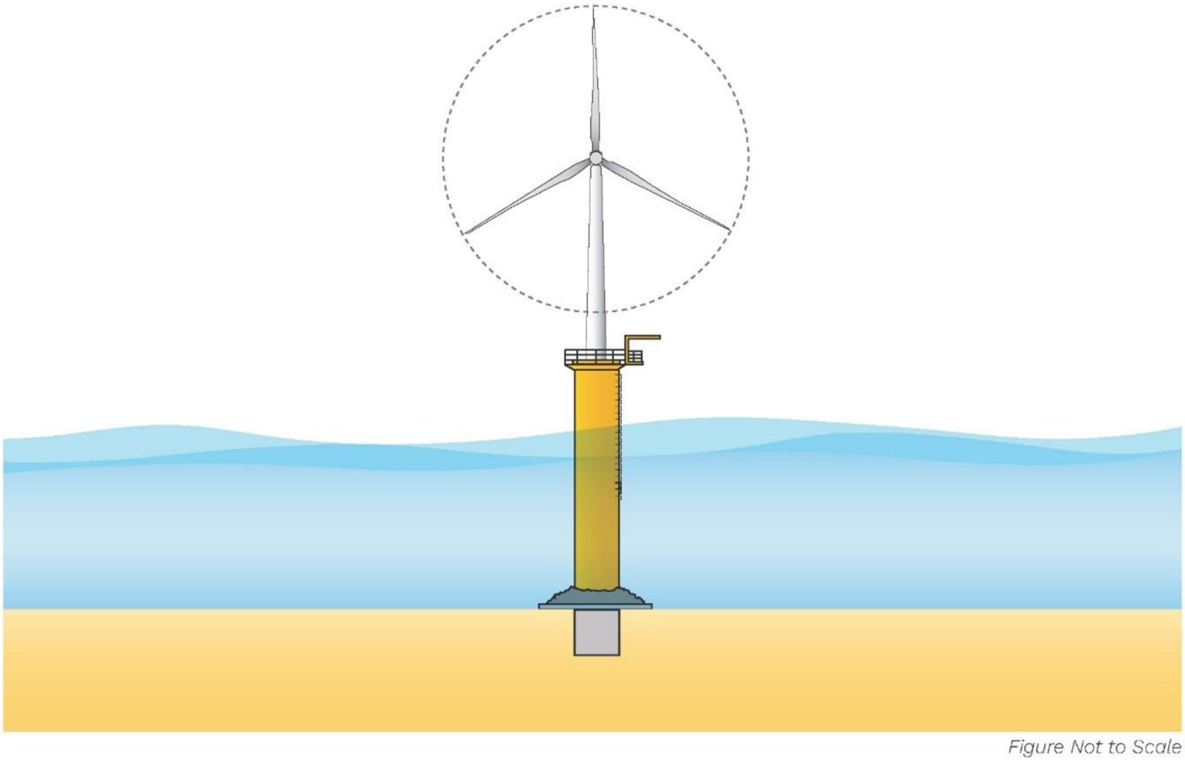


Figure E5.1: Monopile Foundation Design

E4.2 Under Steady Currents

E4.2.1 Breusers *et al.* (1977) presented a simple expression for scour depth under live-bed scour (i.e. scour occurring in a dynamic sediment environment) which was extended by Sumer *et al*. (1992) who assessed the statistics of the original data to show that:

$$\frac{S_c}{D} = 1.3 \pm \sigma_{Sc/D}$$

Equation 3

E4.2.2 Where $\sigma_{Sc/D}$ is the standard deviation of observed ratio Sc/D. Based on the experimental data, $\sigma_{Sc/D}$ is approximately 0.7, hence, 95% of observed scour falls within two standard deviations, i.e., in the range 0 < Sc/D < 2.7, with a central value of Sc = 1.3 D (as also recommended in DNV, 2016).

E4.2.3 Based on the central value Sc = 1.3D, the maximum equilibrium depth of scour for a 13 m (15 MW option) and 15 m (25 MW option) diameter monopile is estimated to be 16.9 m and 19.5 m, respectively.

E4.3 Under Waves and Combined Wave-Current Forcing

E4.3.1 The mechanisms of scour associated with wave action are limited when the oscillatory displacement of water at the seabed is less than the length or size of the structure around which it is flowing. This ratio is typically parameterised using the Keulegan-Carpenter (KC) number:

$$KC = \frac{U_{0m}T}{D}$$

Equation 4

E4.3.2 Where U_{0m} is the peak orbital velocity at the seabed (e.g. using methods presented in Soulsby, 1997) and Tz is the corresponding wave period. Sumer and Fredsøe (2001) found that for KC < 6, wave action is insufficient to cause significant scour in both wave alone and combined wave-current scenarios.

E4.3.3 The value of U_{0m} for given (offshore or deep water) wave conditions depend upon the local water depth, which varies between approximately 53 to 94 m within the array due to variations in absolute bathymetry and relative water level; the influence of shoaling and wave breaking have been ignored in the present study (a conservative assumption).

E4.3.4 Values of KC are less than 6 over the full expected range of tidally affected water depths (approximately 53 to 94 m) and extreme wave conditions (Table E4.1) expected across the site across the site. Therefore, it is predicted that waves do not have the potential to contribute to scour development around the base of the monopile foundations.

Table E4.1: Extreme Omni-Directional Wave Conditions Considered

Return Period (years)	Significant Wave Height, Hs (m)	Zero Crossing Period, Tz (s)
1:1	8.4	7.9
1:10	10.9	8.9
1:50	12.2	9.5

E5 Scour Assessment Method: Wind Turbine Jacket Foundations on Pin Piles

E5.1.1 Above the seabed jacket foundations (Figure E5.2) comprise a lattice of vertical primary members (up to 4.3 m diameter for the 4-legged jacket and up to 4.5 m for the 3-legged jacket) and diagonal cross-member bracing; it is assumed that either no near-bed horizontal cross-member bracing is required, or that it is sufficiently high above the bed to not induce significant local scour. The 4-legged and 3-legged jacket foundations will have a nominally square plan view cross-section with base edge dimensions of 35 m to 43 m.

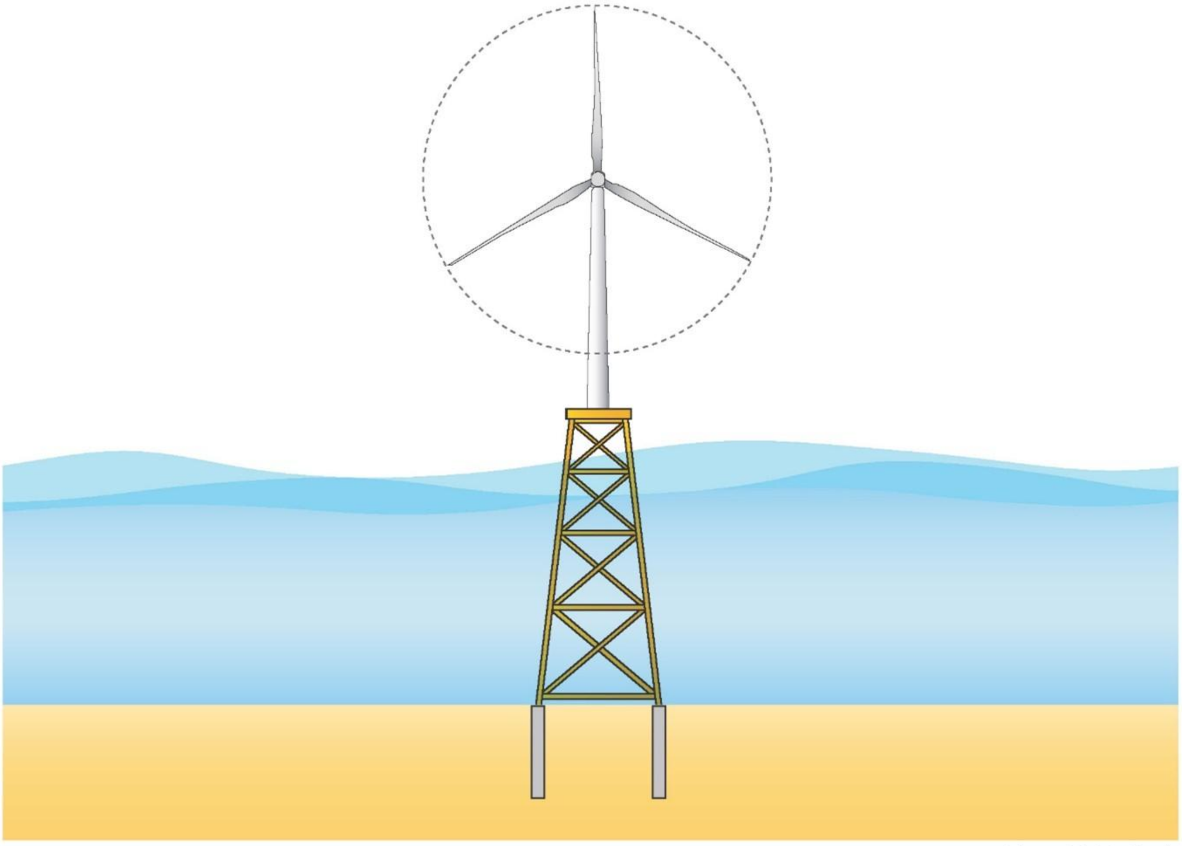


Figure E5.2: Piled Jacked Foundation Design

E5.1.2 The jacket foundation is anchored to the seabed at each corner by a pile driven into the seabed, up to 5 m in diameter for the 4-legged and up to 4.5 m in diameter for the 3-legged jackets.

E5.1.3 A jacket foundation structure may result in the occurrence of both local and group or global scour. The local scour is the local response to individual structure members. Whereas global scour is the formation of a depression around the entire structure.

E5.2 Under Steady Currents

E5.2.1 Under steady currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using methods and equations developed for monopiles, described in the section above, unless significant interaction between individual members occurs. The potential for such interaction is discussed below.

E5.2.2 For a jacket the main scour development will be in proportion to the size of the largest exposed member near to the seabed. For the 4-legged and 3-legged jacket case, the largest exposed member will have a diameter of up to 4.3 m and 4.5 m, respectively. Using Equation 3, the scour depth for the largest 4-legged and 3-legged jacket foundation is therefore estimated as 5.6 m and 5.9 m, respectively.

E5.2.3 In the case of currents, inter-member interaction has been shown to be a factor when the gap to pile diameter ratio (G/D) is less than three. In this case limited experiments by Gormsen and Larson (1984) have shown that the scour depth might increase by between 5% and 15%. However, in the case of 4-legged and 3-legged piled jackets considered for Bowdun the gap ratio for members at the base of the jacket foundation structure is much greater than three, and so no significant in-combination change is expected.

E5.2.4 Empirical relationships also presented in Sumer and Fredsøe (2002) indicate that the depth of group scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket foundation (2 x 2 piles/legs) can be approximated as 0.4 D (i.e. for the 4-legged jacket approximately 2.2 m based on 4.3 m diameter jacket leg and for the 3-legged jacket approximately 2.3 m based on 4.5 m diameter jacket leg). On the basis of visual descriptions of group scour pits, their extent from the edge of the structure is estimated as half the width of the structure and following a broadly similar plan shape to that of the jacket foundation (i.e. square).

E5.2.5 Together, the predicted maximum scour depth at the corner piles (4-legged = 5.6 m; 3-legged = 5.9 m) and the group scour (4-legged = 2.2 m; 3-legged = 2.3 m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6 m and 3.6 m were observed below jacket structures in the Gulf of Mexico (although these could potentially be constrained from the maximum possible equilibrium scour depth by environmental factors and could also be subject to uncertainties in the seabed reference datum against which to measure the scour).

E5.2.6 On the basis of the proposed jacket design, the diagonal bracing members are not predicted to induce seabed scouring due to the distance of separation from the seabed.

E5.1 Under Waves and Combined Wave-Current Forcing

E5.1.1 Values of KC (Equation 4) are less than six over the full expected range of tidally affected water depths (approximately 53 m to 94 m) and extreme wave conditions (Table E4.1) expected across the site across the site. Therefore, it is predicted that waves do not have the potential to contribute to scour development around the base of the jacket foundations.

E5.1.2 The diagonal bracing members will have a smaller diameter and so a larger KC value. However, they are again not predicted to induce seabed scouring due to the likely distance of separation from the seabed. For moderate KC numbers a sufficient distance to avoid scour is approximately one diameter for a horizontal member, increasing to approximately three diameters under increasing KC numbers.

E5.1.3 As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

E6 Scour Assessment Method: Wind Turbine Jacket Foundations on Suction Buckets

E6.1.1 The 3-legged jacket foundation, comprised of a lattice of vertical primary members (up to 4.5 m diameter), is anchored to the seabed at each corner by a suction bucket, up to 19 m in diameter and 1.5 m in height above the seabed.

E6.1.2 A jacket foundation structure may result in the occurrence of both local and group or global scour. The local scour is the local response to individual structure members. Whereas global scour is the formation of a depression around the entire structure.

E6.1 Under Steady Currents

E6.1.1 Under steady currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using methods and equations developed for monopiles, described above, unless significant interaction between individual members occurs. The potential for such interaction is discussed below.

E6.1.2 For a jacket the main scour development will be in proportion to the size of the largest exposed member near to the seabed. For the 3-legged suction bucket jacket case, the largest exposed member will have a diameter of up to 4.5 m. Using Equation 3, the scour depth for the largest 3-legged suction bucket jacket foundation is therefore estimated as 5.9 m.

E6.1.3 In the case of currents, inter-member interaction has been shown to be a factor when the gap to pile diameter ratio (G/D) is less than three. In this case limited experiments by Gormsen and Larson (1984) have shown that the scour depth might increase by between 5% and 15%. In the case of 3-legged suction bucket jackets considered for Bowdun the gap ratio for memes at the base of the jacket foundation structure is less than three (43 m/19 m), so a 15% increase is applied to the scour depth calculated from Equation 3, making the adjusted scour depth 6.7 m.

E6.1.4 Empirical relationships also presented in Sumer and Fredsøe (2002) indicate that the depth of group scour (measured from the initial sediment surface to the new sediment surface surrounding local scour holes) for an array of piles similar to a jacket foundation (2 x 2 piles/legs) can be approximated as 0.4 D (i.e. for the 3-legged jacket approximately 2.3 m based on 4.5 m diameter jacket leg). On the basis of visual descriptions of group scour pits, their extent from the edge of the structure is estimated as half the width of the structure and following a broadly similar plan shape to that of the jacket foundation (i.e. square).

E6.1.5 Together, the predicted maximum scour depth at the corner piles (3-legged = 6.7 m) and the group scour (3-legged = 2.3 m) is conservatively consistent with evidence from the field reported in Whitehouse (1998), summarising another report that scour depths of between 0.6 m and 3.6 m were observed below jacket structures in the Gulf of Mexico (although these could potentially be constrained from the maximum possible equilibrium scour depth by environmental factors and could also be subject to uncertainties in the seabed reference datum against which to measure the scour).

E6.1.6 On the basis of the proposed jacket design, the diagonal bracing members are not predicted to induce seabed scouring due to the distance of separation from the seabed.

E6.2 Under Waves and Combined Wave-Current Forcing

E6.2.1 Values of KC (Equation 4) are less than six over the full expected range of tidally affected water depths (approximately 53 m to 94 m) and extreme wave conditions (Table E4.1) expected across the site across the site. Therefore, it is predicted that waves do not have the potential to contribute to scour development around the base of the jacket foundations.

E6.2.2 The diagonal bracing members will have a smaller diameter and so a larger KC value. However, they are again not predicted to induce seabed scouring due to the likely distance of separation from the seabed. For moderate KC numbers a sufficient distance to avoid scour is approximately one diameter for a horizontal member, increasing to approximately three diameters under increasing KC numbers.

E6.2.3 As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

E7 Scour Assessment Method: OSP Jacket Foundations on Pin Piles

E7.1.1 Above the seabed OSP jacket foundations comprise a lattice of vertical primary members and diagonal cross-member bracing; it is assumed that either no near-bed horizontal cross-member bracing is required, or that it is sufficiently high above the bed to not induce significant local scour. The jacket foundation is anchored to the seabed at each corner by a pile driven into the seabed and extending above the seabed, there piles are up to 4.5 m in diameter for all OSP jacket options. All OSP foundations have a nominally square plan view cross-section with base edge dimensions of 48 m.

E7.1.2 A jacket foundation structure may result in the occurrence of both local and group or global scour.

E7.2 Under Steady Currents

E7.2.1 Under steady currents alone, the equilibrium scour depth around the vertical members of the structure base can be assessed using methods and equations developed for monopiles, unless significant interaction between individual members occurs. The potential for such interaction is discussed below.

E7.2.2 For a jacket the main scour development will be in proportion to the size of the largest exposed member near to the seabed. For the 4-/6-/8-legged the largest near-bed exposed member will have a diameter of up to 4.5 m. Using Equation 3, the scour depth is therefore estimated as 5.9 m, respectively.

E7.2.3 In the case of currents, inter-member interaction has been shown to be a factor when the gap to pile diameter ratio (G/D) is less than three. In this case limited experiments by Gormsen and Larson (1984) have shown that the scour depth might increase by between 5% and 15%. However, in the case of 4-legged, 6-legged and 8-legged piled jackets considered for OSPs the gap ratio for members at the base of the jacket foundation structure is greater than three, and so no significant in-combination change is expected.

E7.2.4 Empirical relationships indicate that the depth of group scour for an array of piles similar to a jacket foundation can be approximated as 0.4 D (Sumer and Fredsøe, 2002). For the 4-/6-/8-legged jacket approximately 1.8 m based on 4.5 m diameter pile. On the basis of visual descriptions of group scour pits, their extent from the edge of the structure is estimated as half the width of the structure and following a broadly similar plan shape to that of the jacket foundation (i.e. square).

E7.2.5 On the basis of the proposed jacket design, the diagonal bracing members are not predicted to induce seabed scouring due to the distance of separation from the seabed.

E7.3 Under Waves and Combined Wave-Current Forcing

E7.3.1 Values of KC (Equation 4) are less than six over the full expected range of tidally affected water depths (approximately 53 m to 94 m) and extreme wave conditions (Table E4.1) expected across the site across the site. Therefore, it is predicted that waves do not have the potential to contribute to scour development around the base of the OSP jacket foundations.

E7.3.2 The diagonal bracing members will have a smaller diameter and so a larger KC value. However, they are again not predicted to induce seabed scouring due to the likely distance of separation from the seabed. For moderate KC numbers a sufficient distance to avoid scour is approximately one diameter for a horizontal member, increasing to approximately three diameters under increasing KC numbers.

E7.3.3 As such, little or no significant additional scour is predicted to result from waves, either alone or in combination with currents.

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